Power Electronics

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Lecture - 15

Front-End Ac to Dc Converter - Simulation Study

In the last two three classes, we were talking about ac to dc converter, front end ac to dc converter with unity power factor. So, we start with how we can make use of this converter so that we can have an ac to dc converter with a PWM control and we do not have to resort high very high frequency PWM, without resorting to very high frequency PWM switching and using two converters and with a phase shifted sine and triangle modulating signals appropriately some of the lower harmonics we could suppress.

So, the harmonics we were able to suppress was the harmonics at the fc and its side bands and then the harmonics and the side bands of 2 fc and we were using an fc of around 11 times the mains. Now, then we discussed how that inductance we can design and the output capacitor how we can design, then how we will go for the PWM signal, sine triangle you have drawn on the wave forms, then how we can draw a closed loop schematic of the whole control scheme, then how we can design our controller; all those things we have designed for a particular converter input specification.

Now, let us see, now all the design part is over; let us say our design is correct or not. So, we will go to our simulation now.

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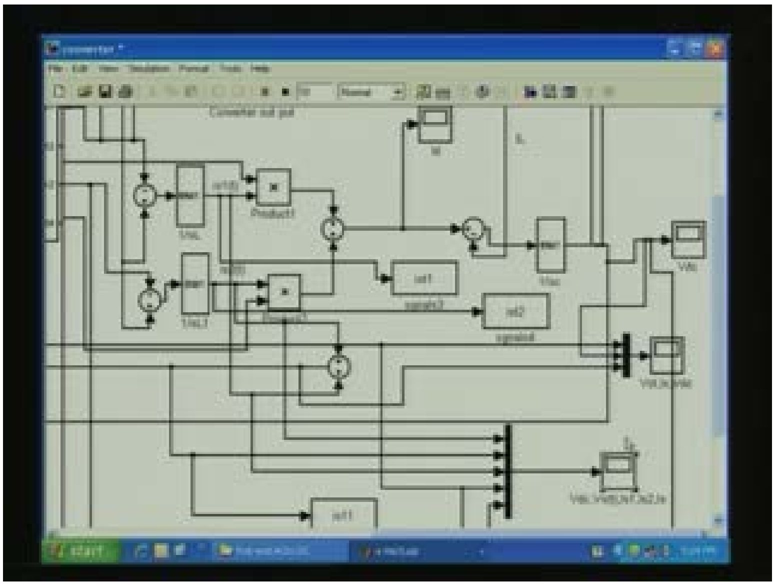

So, if you see here, this is our front end converter. So, this is our input reference; input reference when we give 10 volts, we want our output voltage of 2800 volts. Now, this output we are giving a feed back here that is we are sensing the output dc and feed back here and we are controlling it.

So, before coming to the whole controller, let us first see whether it is working, let us start it quickly; then we will come to the various controllers. So, the various ports are available; this is our total dc link current, here we can observe here, here we can see separate output dc voltage, here we can see the output voltage, total transformer input primary current and the primary reference voltage. And here, we can see the total output V_{DC} means output dc voltage, then the input voltage, then the two converters due to PWM that current and the total current. So, let us start it now and let us see how it works, we will open this one.

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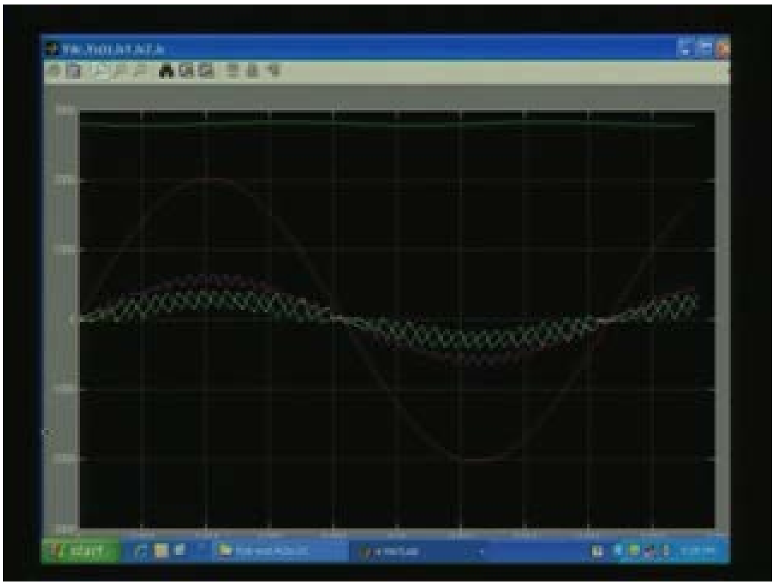

See, if you see your static, this is the capacitor voltage, this is the starting transient, it will stabilise soon. If you see here, this red line that is this one, this is our input mains, sinusoidal representation. Then we can see the three sets of current here. This violet current, this is the total transformer input current that is this one and these two are the two converter currents. So, if you can see the two converter currents it has more ripple than the primary side. Another thing you should notice that one is this power is from the source ac side to the dc side with the nearly unity power factor. If you see here, it is nearly unity power factor and our capacitor voltage is nearly 2800 voltage.

Let us, so this X axis I put some lower time scheme so that I want to see the repel and the current.

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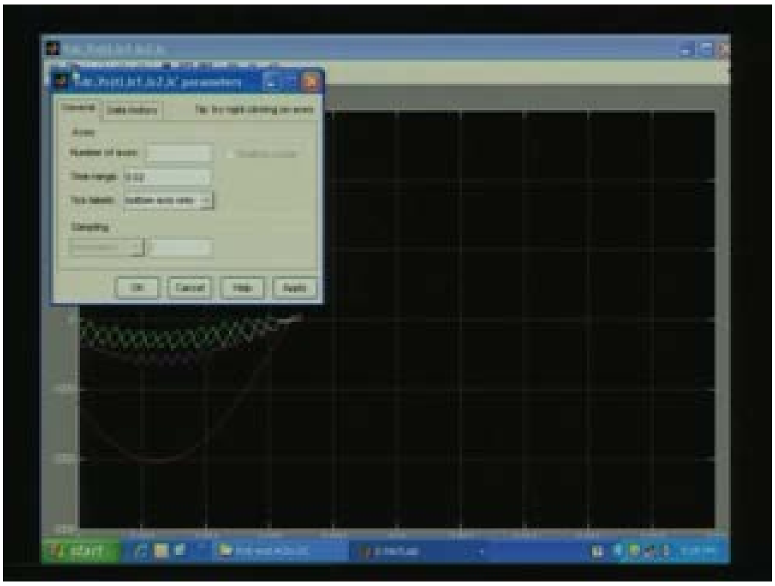

Now, let us see more number of cycles in a cycle; instead of 0.2, I will make it here, apply and refer.

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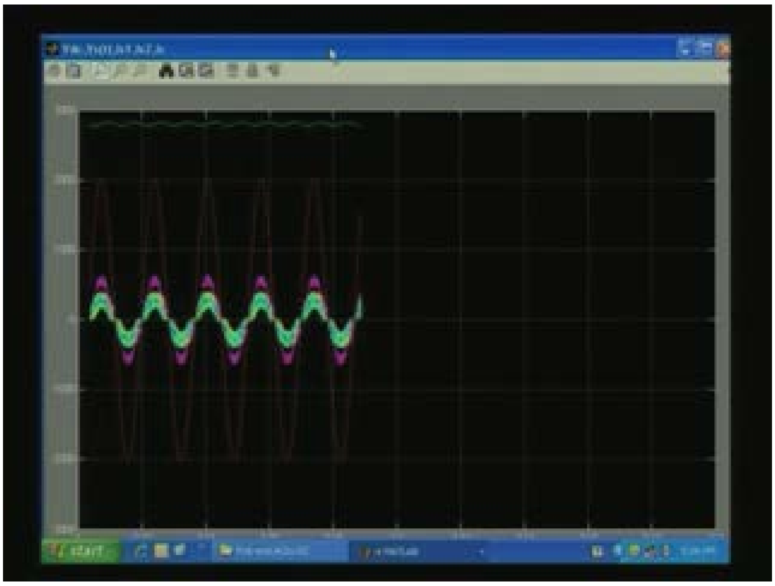

So, if you see here, see the capacitor repel; so we have designed for a delta v of 5%, so it is within the 5% thing and here is the mains voltage run and the two converters and the transformer primary curve. So, transformer primary current if you see, the repel is highly negligible. Now here, I want to see, quickly I want to reverse it; let us see whether we can do it.

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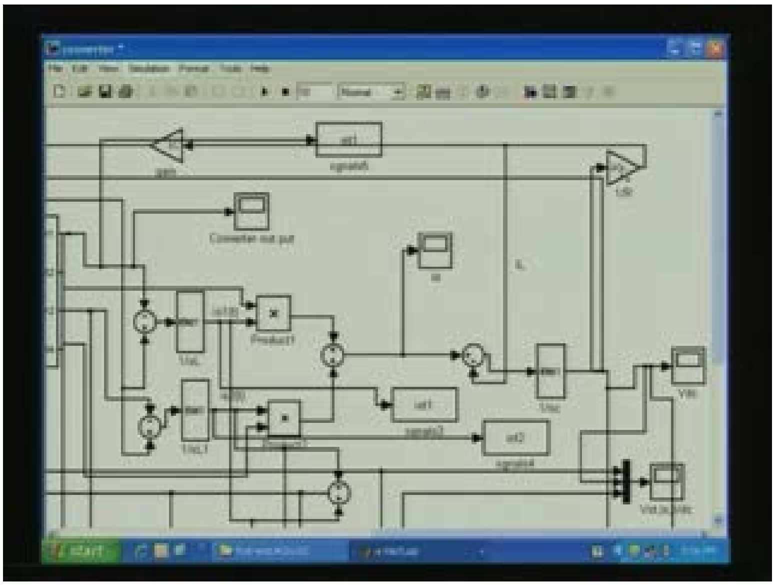

Simulation, I pause it; now, I will try to change the load resistance. Load resistance we have represented as a resistive load, 1 by r; this is the current feedback. So, to make it regeneration load, I will make it negative that is how we can make it the regenerative quickly, regeneration.

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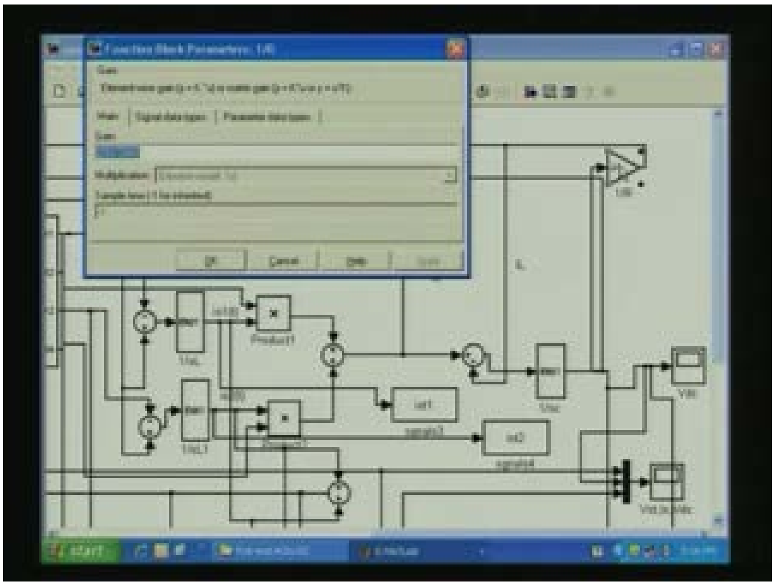

So, load is made negative, apply, then simulation, continue.

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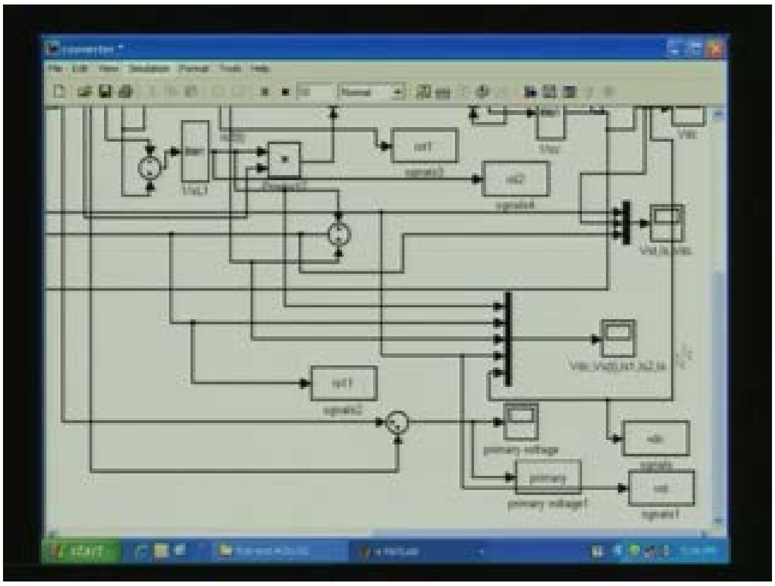

Let us see our converter block here. What happened to this one?

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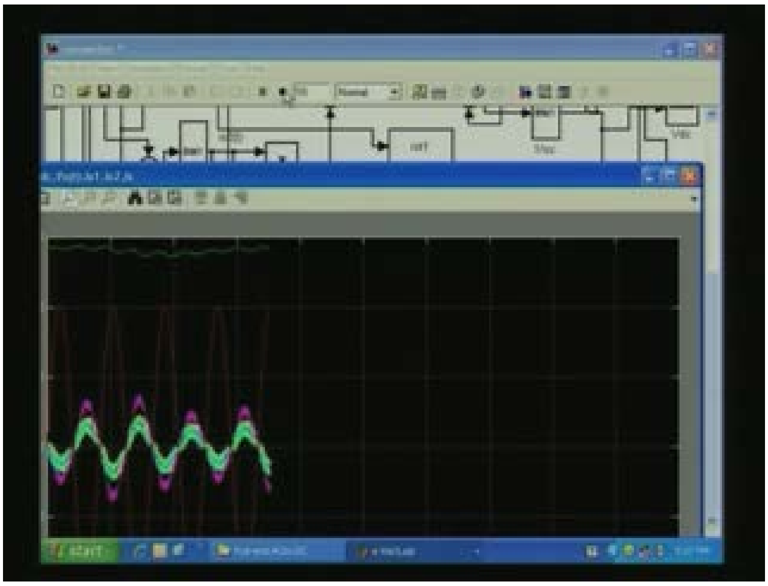

See, immediately it reverses because in the same screen it has happened, see immediately it reverses, you can see here. During the power reversal, the transient slowly it would slide up. See, there is fluctuation in the capacitor voltage but it stabilises. Now, if you see here, the power flow is negative, opposite, in the reversed direction. Now, it will stabilise soon; see capacitor voltage is stabilised and input control was stabilised within few cycle, one or two cycle. So, everything is stabilised, quickly powered.

Here if you see, it is the input voltage and the currents are nearly 180 degree phase shifted that means power flow is opposite direction. Now, so that our convertor model is working; now only fine tuning you can do so that these transients however we can control it. Now, let us stop this one and let us go to our model so that a detail study of the model, how we can model it, we will get a field for it.

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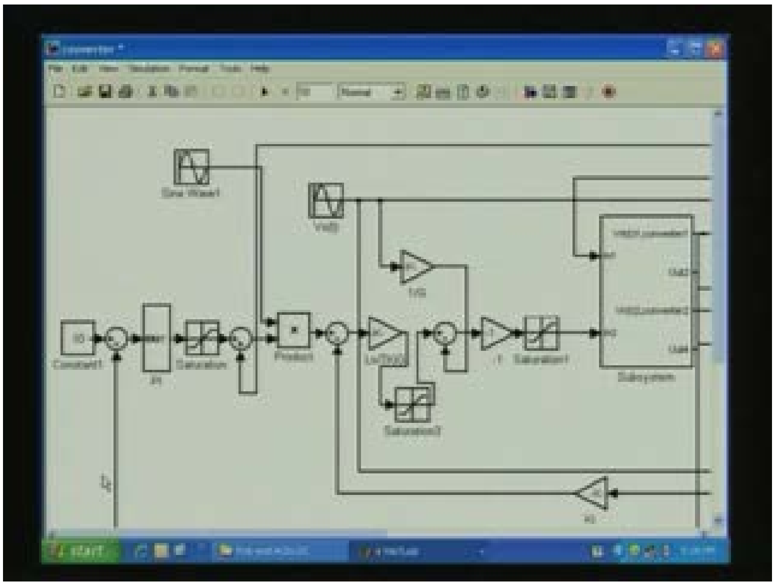

As I told, so this is our constant 10 volt that is our input reference, this is Matlab Simulink block, you can get this block and if u click here, the constant value we can mention here. So, we can measure 10 volts.

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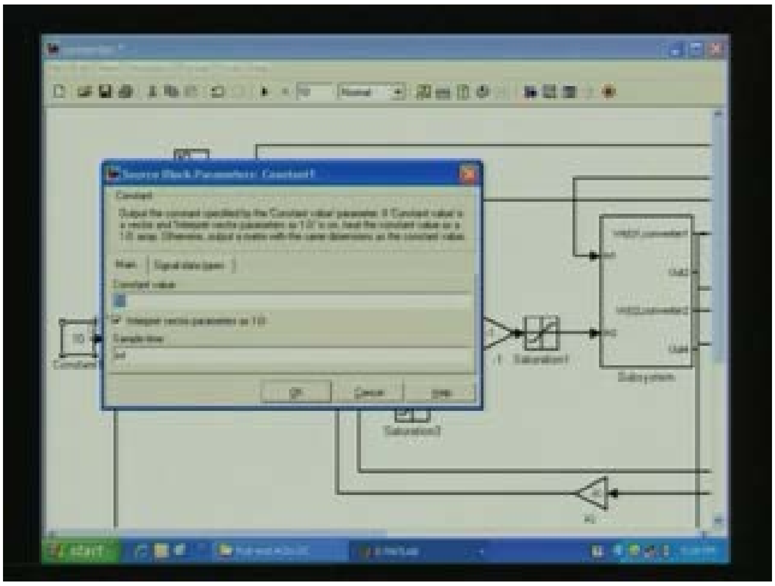

So this, in Matlab we can extract, we can stimulate the whole thing based on the actual voltages but here if you see, our controller will be in the real practice, it will be on the plus or minus or plus or minus of 10 volts plus or minus 15 voltage level, then through the convertor we boost up the output voltage. So, to get the say one to one correspondence with the thing, we will make the block 10 volt and we are giving the feedback here. This feedback is taken from our V_C. How we get the V_C?

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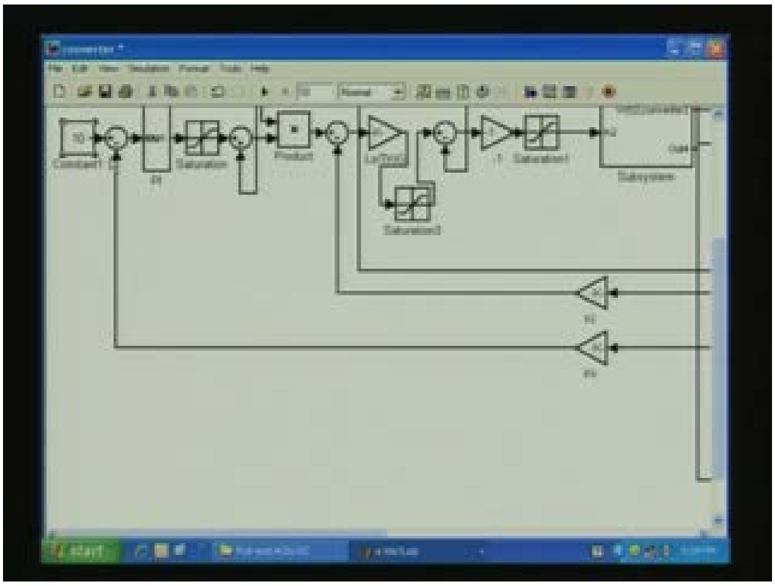

That is this side, V_{dc} will come to that one, this we will, we have taken that one, from there we will step down the voltage that is this one that is the K_V; we will step down so that when 2800 volts comes, here it will be 10 volt. So, any change in the capacitor voltage due to sudden loading or anything, it will act here or whenever if we want to get 2800 volt, suppose you want the output dc only 2000; we can control this one, correspondingly feedback will take care of that one. But here we want of front end ac to dc fixed dc. Now, this is our PI controller.

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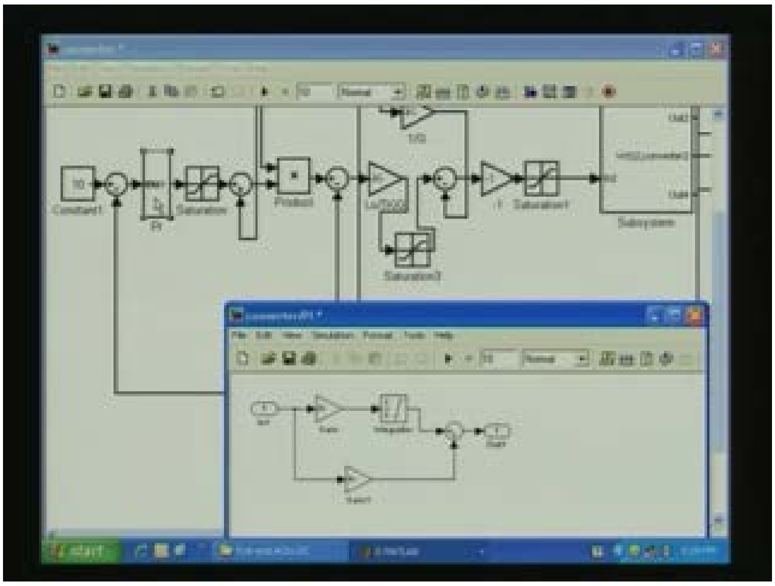

PI controller; see P plus I, so last class I taught, we discussed about the PI controller implementation using analog circuits. There, I mentioned output has to be controlled that means here the output well within, suppose it is analog operational amplifier, it has to be well within the plus 12 minus 12; so to be safe, we will make it plus 10 and minus 10. So here, we give the saturation limit output controller and at the same time, the last time we said the feedback operational amplifier with the set values maximum minimum.

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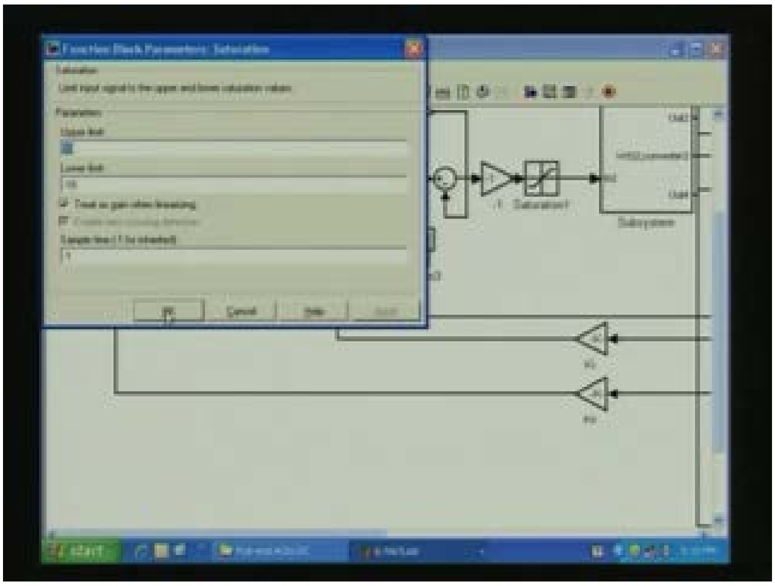

Here, if you see here, we can set upper limit and minus limit block, so easy for simulation. Then PI controller that capacitor saturation I told, so here also there is an integrated … integrator.

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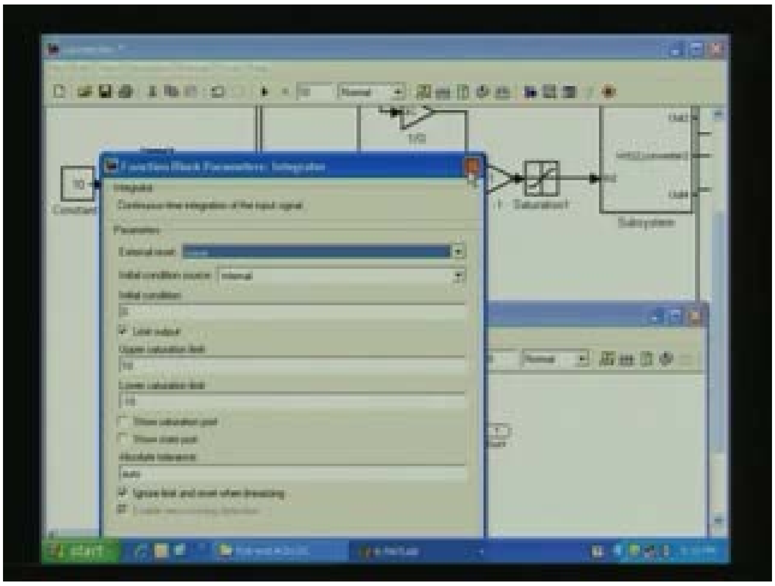

Here if you take integrator, saturation limit we can specify here so that we have specified here then sum here. So, because of this gain, the output also we should limit it that is why this output that is this is the output is the one here, we limit to plus 10 and minus 10.

Now, there is another feedback is coming here, this is called feed forward. It is coming from the current, output load current. See, this PI control, this is coming from the output load current; we are putting a load, for the simulation we are putting a resistive load, this output dc multiply 1 by r gives the load current, again gain, current gain we will give it here.

So, these current gain plus this one when it gives here; so here also, this gain you should properly do it so that the current total reference should be always plus or minus 10 volt level. Now, if you see, this is called feed forward but this we are not talked before. If you see here, this PI controller; we want this PI controller to change whenever the only the capacitor changes or whenever our reference change only, we want this PI controller should act. But if you see, sudden load changes, there is a fluctuation in the capacitor voltage. That can load change will reflect here, then it will gives a required current reference. So, instead of going through this output loop, if we can send the output current, natural practice and then the power balance input power is equal to output power.

So, we know the input voltage, peak value, rms value, sinusoidal we know it, output dc is also known; so from that one, for any sudden load changing or change in load, what is our required input current we can feed forward? So, that we can give it, so this is the total current reference. This current reference, we want unity power factor. This gives for a sinusoidal for the sinusoidal current; what is the peak value? Now, we will generate a sine wave.

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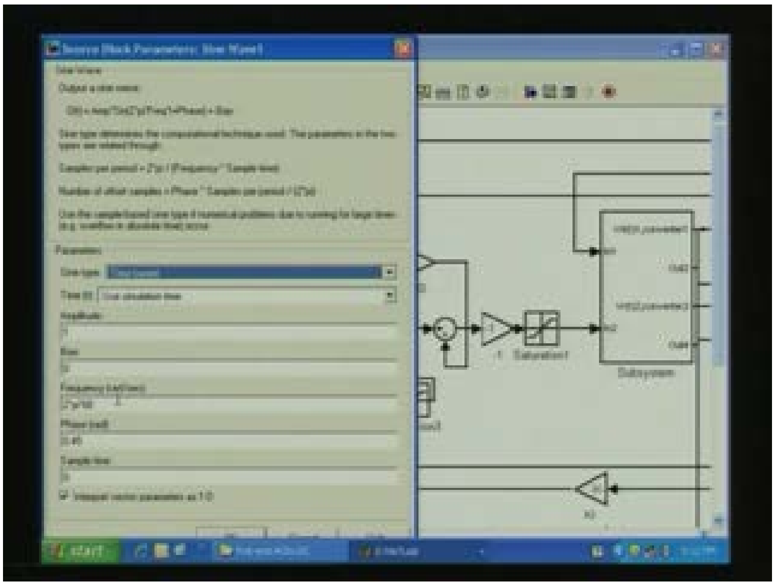

This sine wave is in natural practice, we have to derive from the mains so that it should have the and here we are generating with an amplitude one, so we want only the sine function one and this frequency - 2 pi into 60 that is our main frequency. Then this slight phase lead is adjusted here. As I told here, their phase lead we can adjust such that that is our input mains frequency and this due to, the current which is reference current and feedback current has come to the current loop and we are dealing with sinusoidal current, there is a delay will be there. That delay can be compensated by giving a leads to the reference here that is what we have given; that with trial and error, we can adjust it so that we will get nearly unity power factor.

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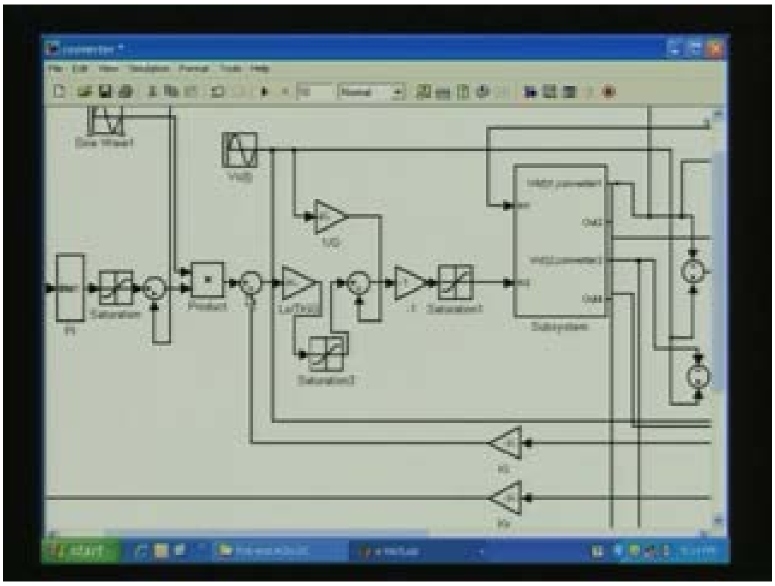

So, it has come here and we are multiplying that one. So, our final current reference is here. Now, current feedback; so if you see here, the current feedback is taken from here, 1 by r. This current feedback, there are two converters; two convertors will give total i_s 1 and i_s 2 input current and this is our, so two converter should equal current. So, this is the total load current. This total current we can take it and divide by the current gain and we can feed it here.

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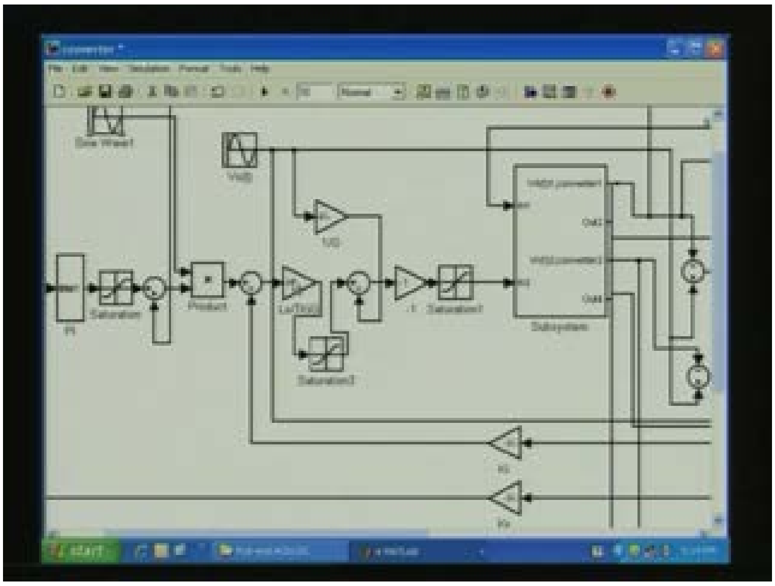

Then, current control loop; controller we said we want only we require only a proportional gain that is ls, here ls is there, l is the inductance. Then t, t is equal to 2 tr we know it; is a K_i current feedback gain, g is the converter gain. So, this we can put it here.

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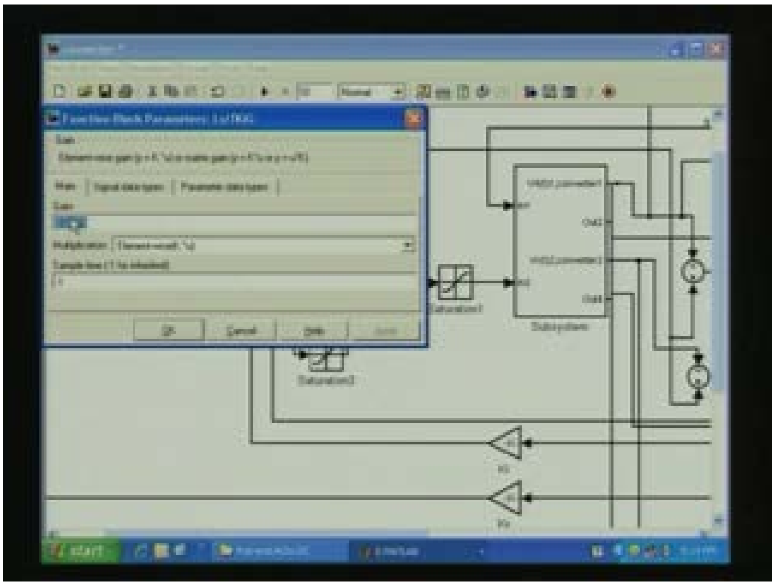

So, if you take the gain factor, we can put this gain here that is what is specified here; so, gain is given here. Then there is a saturation limit here.

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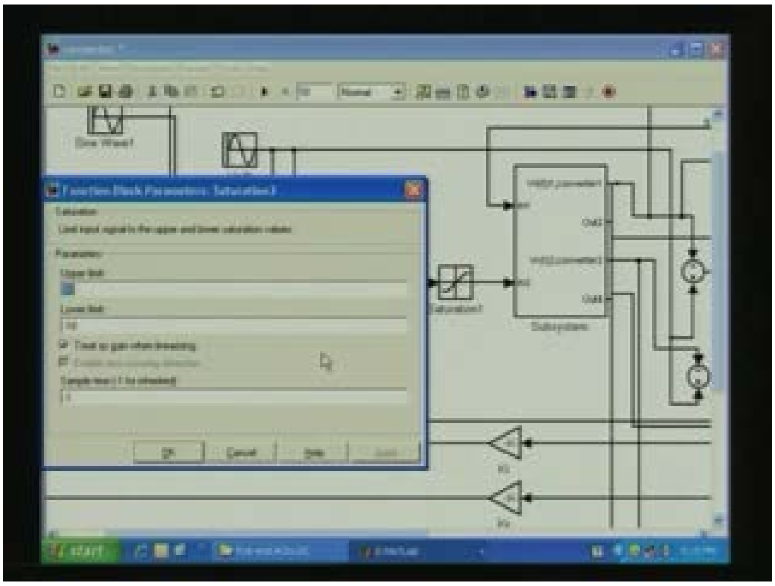

So, here also saturation, we are always saturation limit, we are making plus or minus 10; this will come here. To this one, minus vg; this is coming from our V_S (t) that is our reference voltage. So, this minus vs vg v this one with the saturation, we are giving to the converter as the input. See, here also, this also act as the feed forward. If any change in fluctuation, V_S (t) happens. If it is not here, then it will reflect on the capacitor and then capacitor due to current and then only current loop will adjust.

Instead of that one, we can through a feed forward, we can give it here that is from the standard back converter equation V_S (t) Vr, V_S (t) minus or V_S (t) plus l into di by dt is equal to Vr (t), we can give it here. Now, this also, this is our converter.

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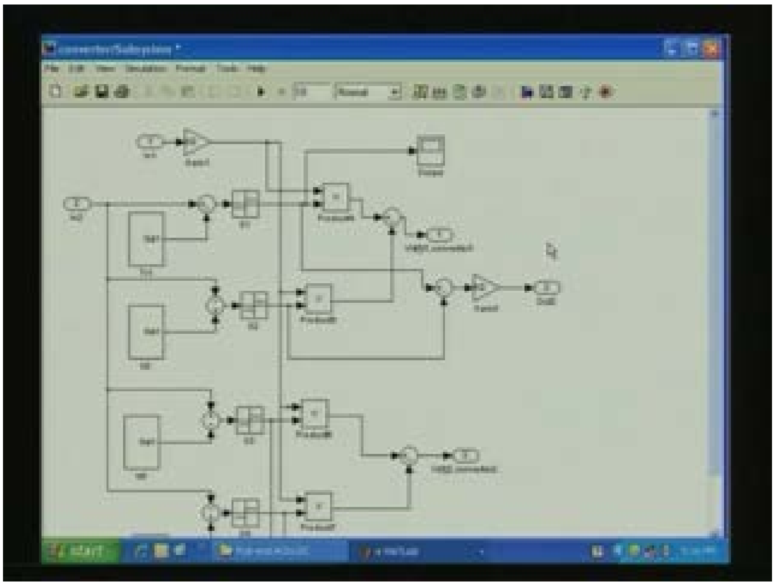

Convertor we have, if you see here, there are two convertor; this input is our V_r (t) reference, this reference is compared with the triangle waveform.

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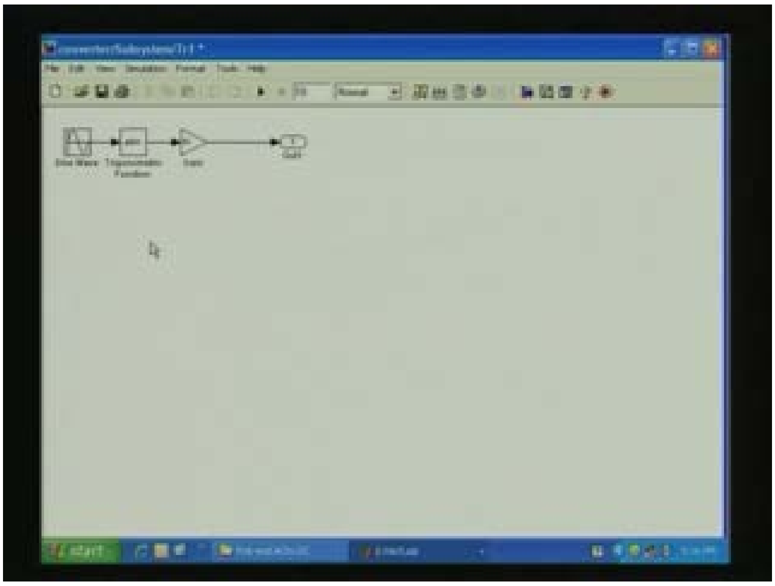

So here, triangle waveform we can generate; first we will generate a sine wave.

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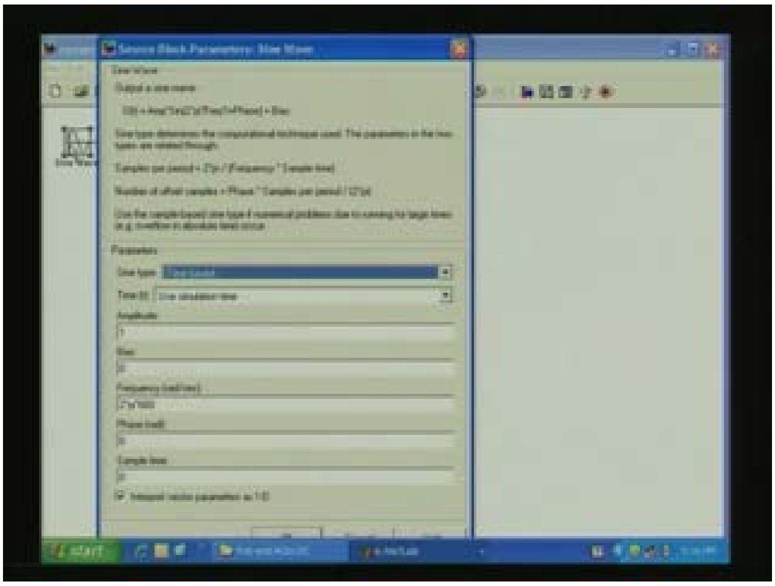

Sine wave multiplied by, the frequency is not 60, 16 multiplied by 11. So, this is 2 pi into 660. This triangle waveform, we will pass through a sine, this arc triangle trigonometric tree function. So, this will automatically, if you give arc sine if you give, it is a triangle waveform which is in phase with the sine waveform. So, the phase shift will not be there.

So, that is why I think, we would not have a triangle waveform which is in synchronised with our mains. So, arc term it comes, it will arc term means it is angle, it will go to the pi value plus minus pi. So, corresponding gain if you do it her, gain multiplicant you can get the triangle waveform which close to whatever the value plus or minus 10 or plus or minus 1; whatever we want here.

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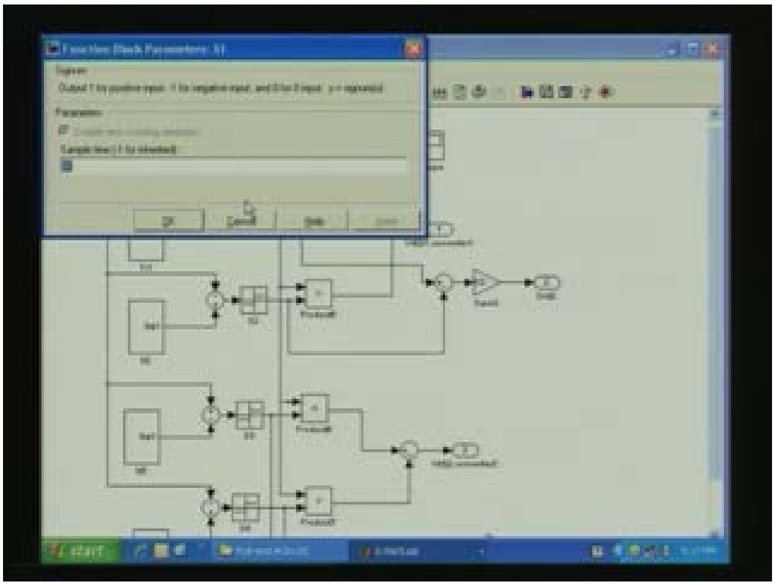

Then this is the logic we will put it here; in this logic if you see, its output one for positive input that means when the error is negative that is the sine is greater than the triangle value or negative that is minus 1 when the sine is less than the triangle value. So, this is the one which we can give it here. So, we will get a PWM waveform.

This PWM waveform going from plus 1 to minus 1 multiplied by V_{dc} by 2 that is our V_{dc}, we know it. So, V_{dc} by 2 plus or minus 1, you will get the pole voltage that is for phase A leg or this is phase B leg waveform here. So, if you see here, this side it will be plus or minus 1 only that multiplied by this one, you will get actual voltage here.

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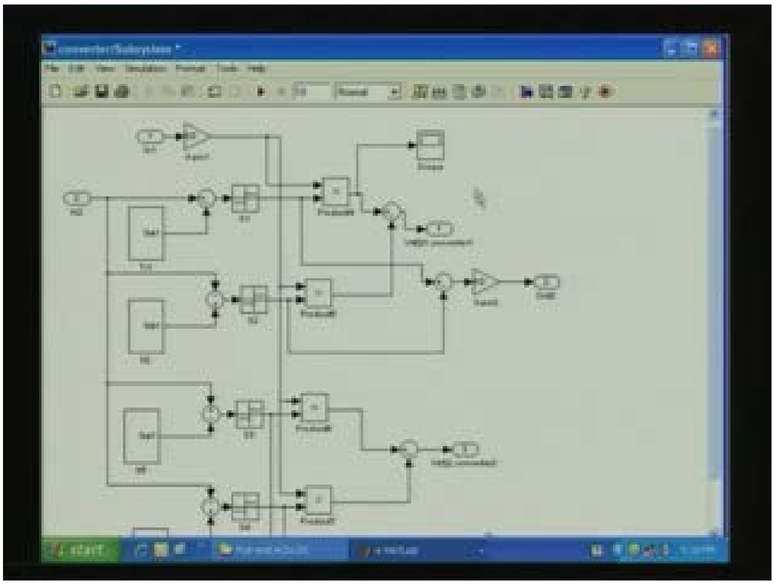

Maybe, we can connect this one to the input side and we can observe that one whether it is working. Now, let us take the axis property also.

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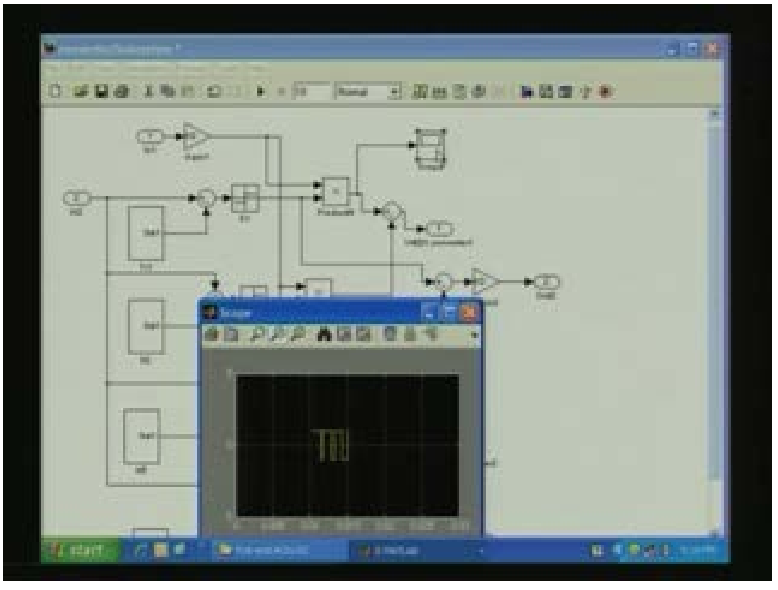

If it is here, it is going plus or minus 1 but if we are multiplying, we have taken from here; so we have to increase the amplitude.

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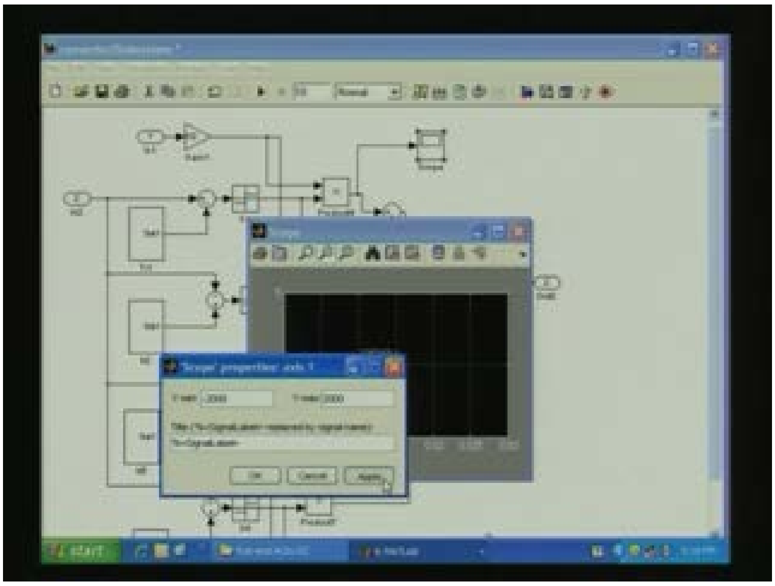

So here, we will change the amplitude, we want minus 3000, here plus or minus Vdc by 2, so 2800. So, we will make it as around half of that one, so approximately 2000 and plus 2000. Now, we will run the system, we will see what is happening in one leg.

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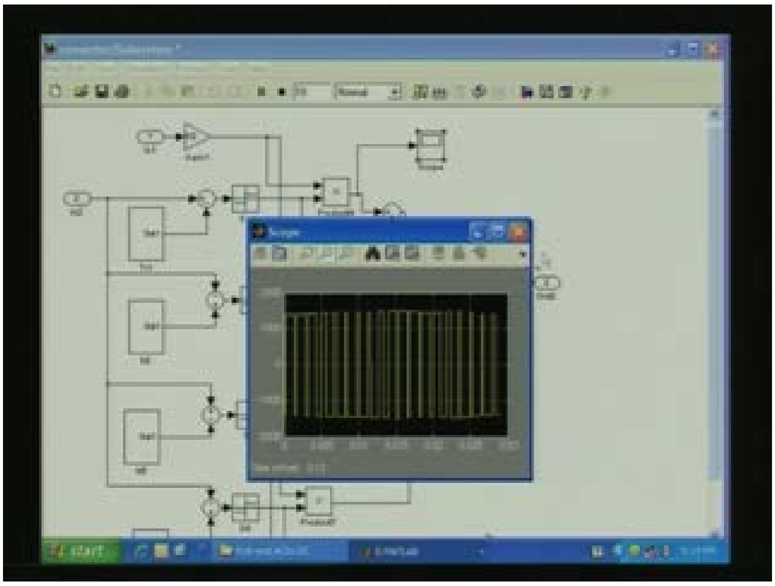

So, if you see, this is the starting, throughout the capacitor has to build up, quickly a capacitor is building, then the pole voltage is a waveform is that starting transient because we initiated. So, once it stabilises, it will go into plus Vdc by 2, minus Vdc by 2; this is for one converter. Now, we will stop this one. So, same way, we have the other converter.

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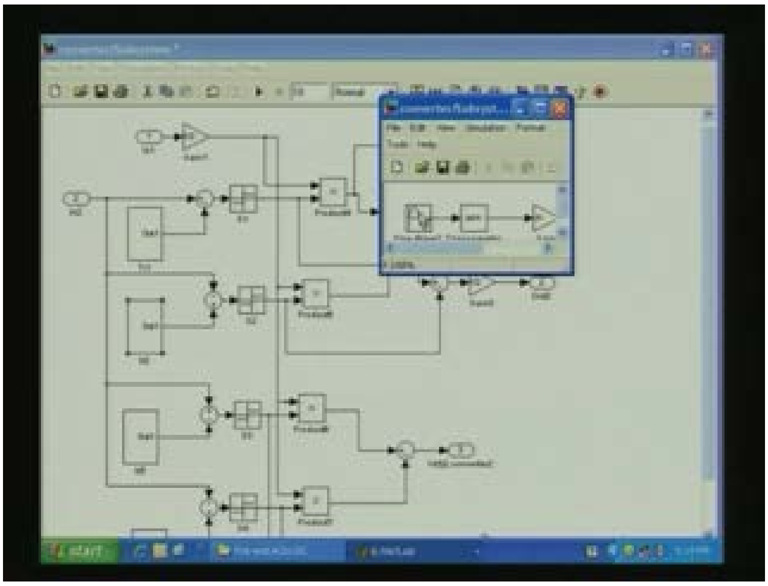

Here in this converter compared to this one, as I told before the sine waveform; this also 2 pi 60 and phase shift we have …

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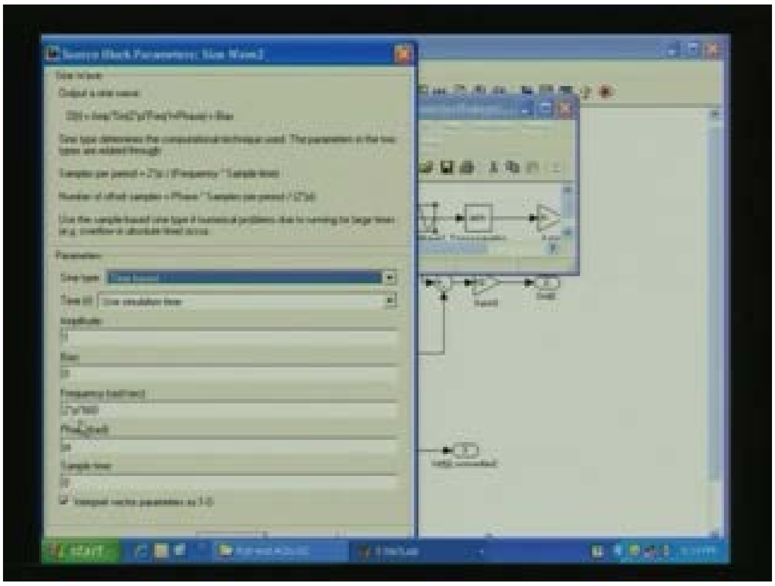

See, here we are making a 180 degree phase shift at triangular waveform that is a phase we are given a pi here. So, compared to previous one and this one, you have phase shift of 180 degree will be there. Again, r tan we will use it this one and with gain, you will get triangle waveform.

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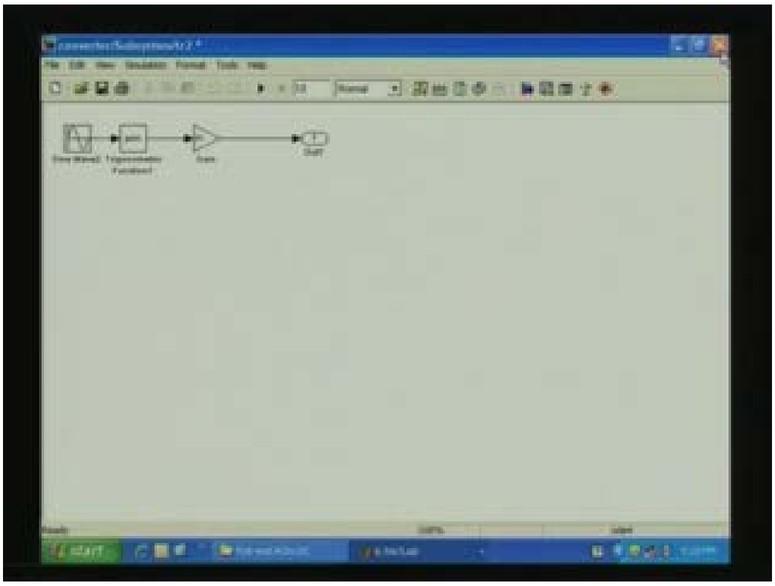

Maybe, we can observe how this triangle waveform looks like.

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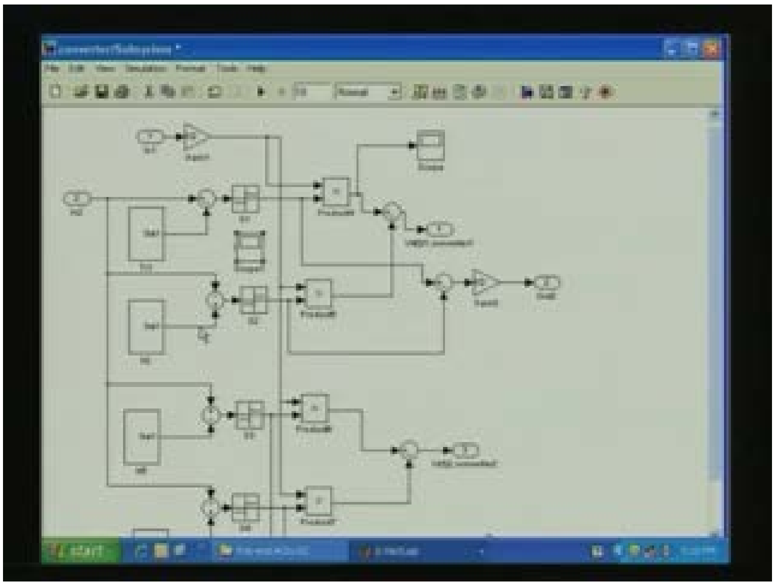

You will copy this one here and two waveforms maybe we can give it here. So, you require a multiplier block.

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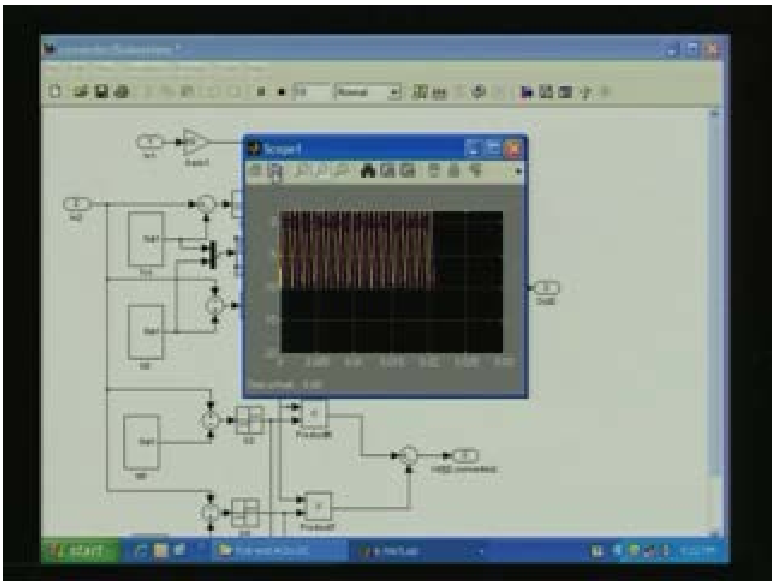

This is the triangle wave form we are seeing here which is 180 degree phase shifted.

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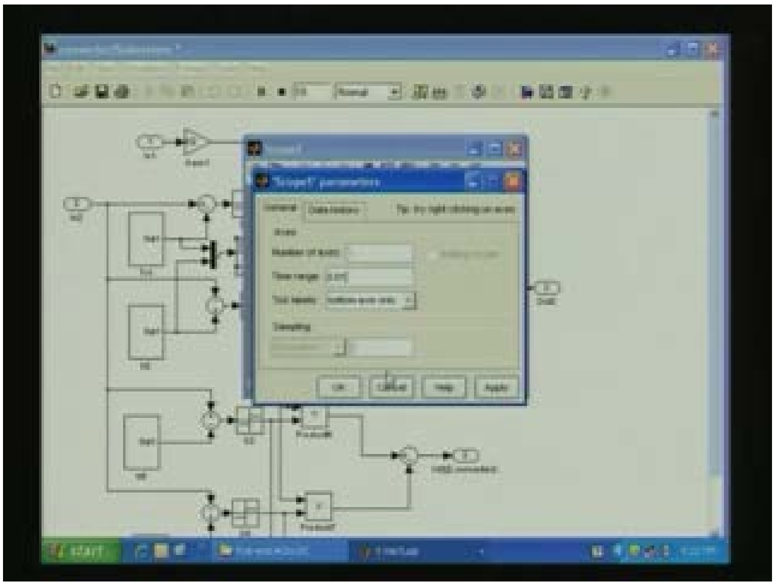

Maybe, we can slightly expand it so that we can see a better waveform of 0.08.

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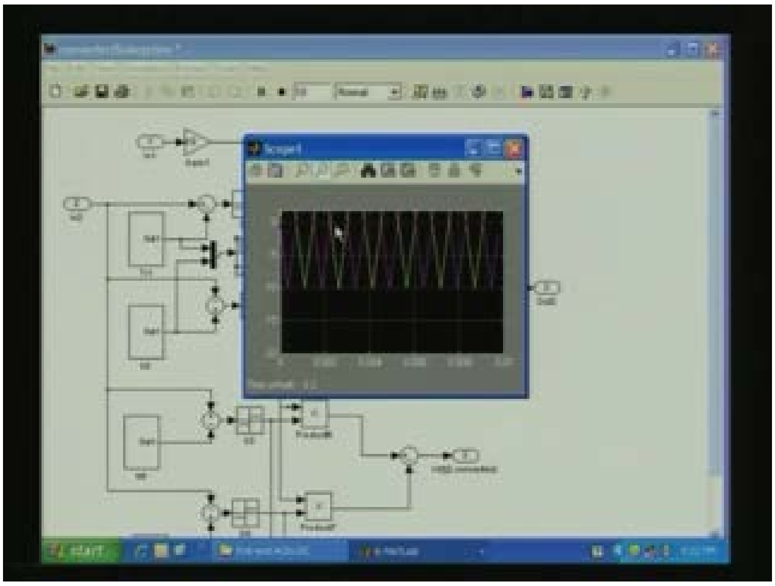

See, the waveforms are opposite each other. So this scale, we will again adjust it here.

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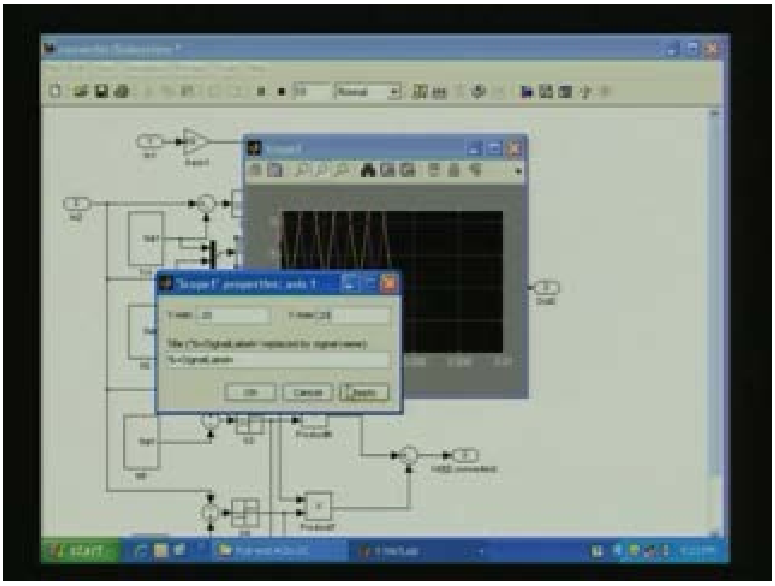

So, that will give you, we will make it 20 here.

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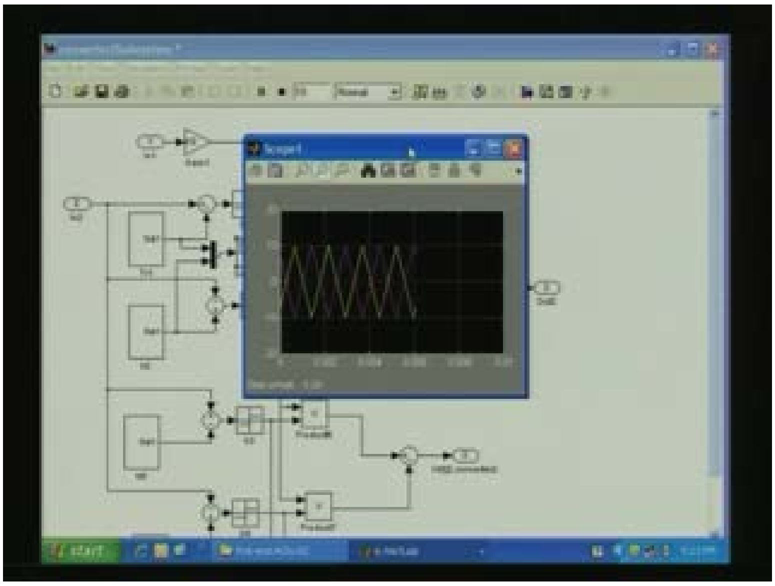

So, two triangles as I told; this is for the converter one, this is for the converter two and this should be 180 degree phase shifted. So, that is taken here as I told here. Now, let us see, for the converter two; converter two we are using the triangle waveform which is 90 degree phase shifted compared to this phase A but these two are again 180 degree phase shifted. So, let us see, whether this is 90 degree phase shifted.

So here, if we go here, we have already pi by two that is a 90 degree phase shift we have entered here. So, that is true.

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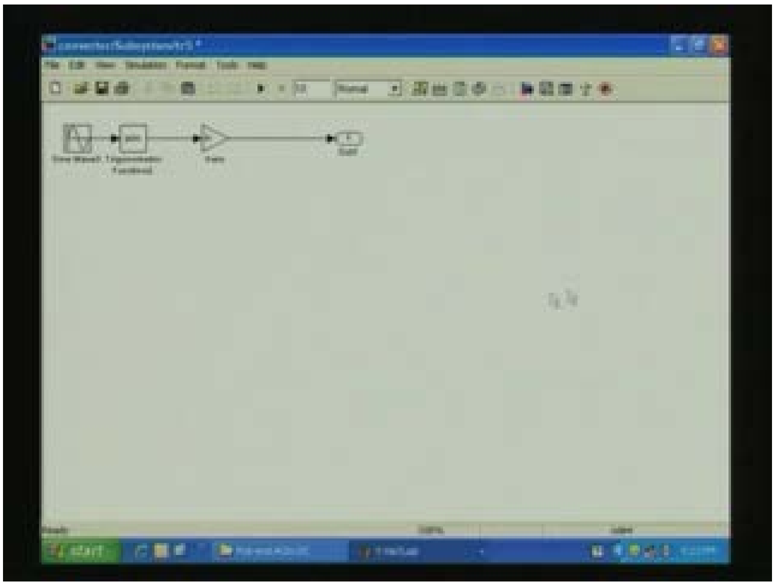

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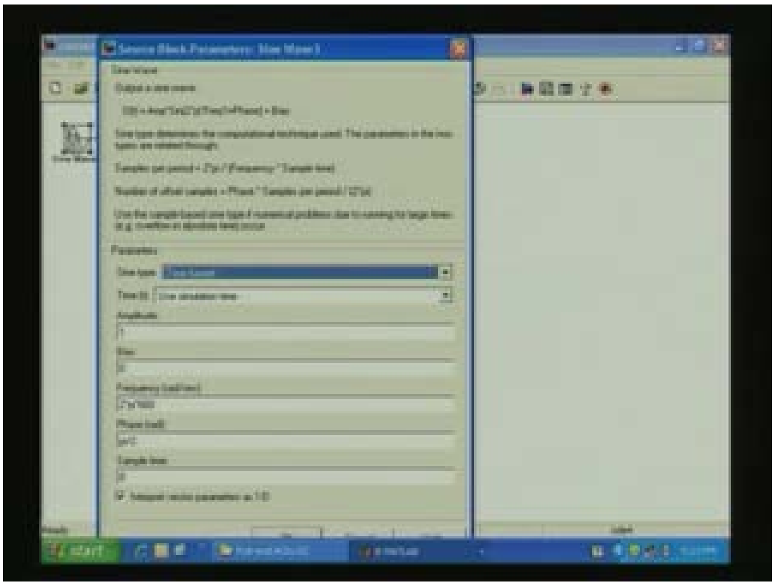

Now, let us see whether simulation it is happening here. So, we will remove this block and you take this one here.

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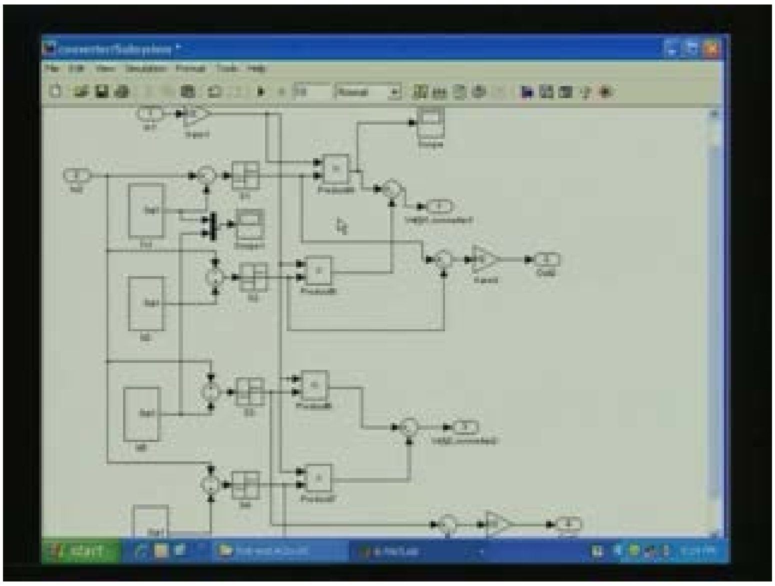

So, these two are for the converter one phase A leg, phase B leg triangle and these for the converter to phase A and phase B. So, for this converter, the triangle waveform should be 180 degree phase shifted, should be 90 degree phase shifted. Let us see now.

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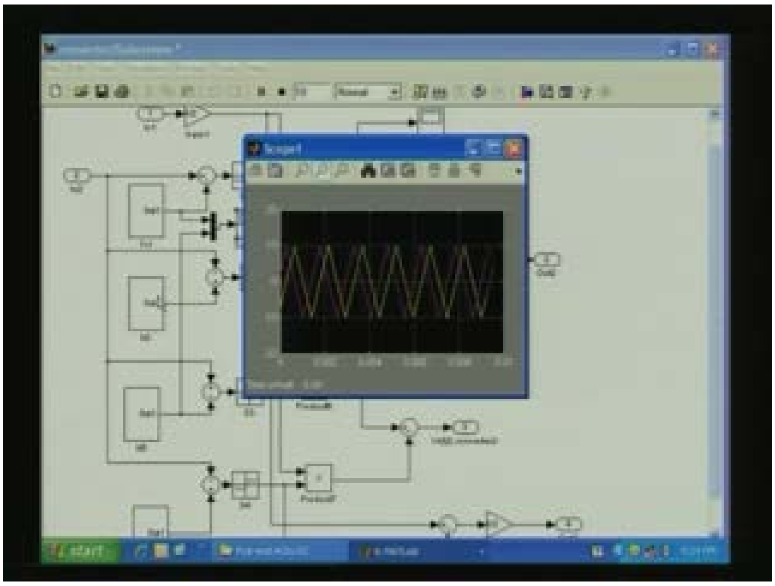

See, these two are 90 degree phase shifted and so these two waveforms, so converter one and converter two, triangle waveform 11 times but 180 degree phase shifted A and B; for converter one and convert two, phase A leg is 90 degree phase shifted. That is what we are seeing it now.

Now, let us stop and let us see whether these two are 180 degree; this is 90 degree and again 180 degree here. So, let us see that one.

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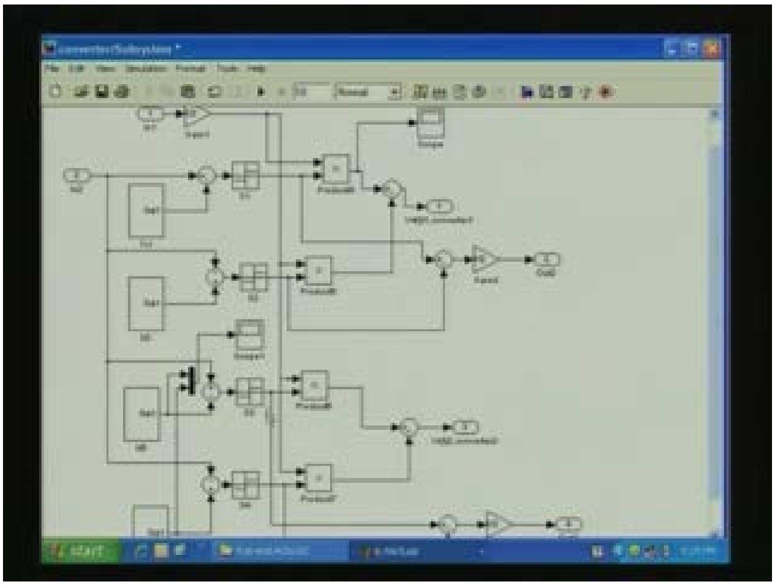

So, we will drag this one, we will delete this one from here and drag it there and then check it. So, with one scope this is called mugs block with we can multiplex, we can two channels or three channels we can put to a scope. So, let us take this one here, this one here, I will take this one here, one is here and this one here. So, let us see, this one would be 180 degree phase shifted. So, this is also 180 degree phase shifted.

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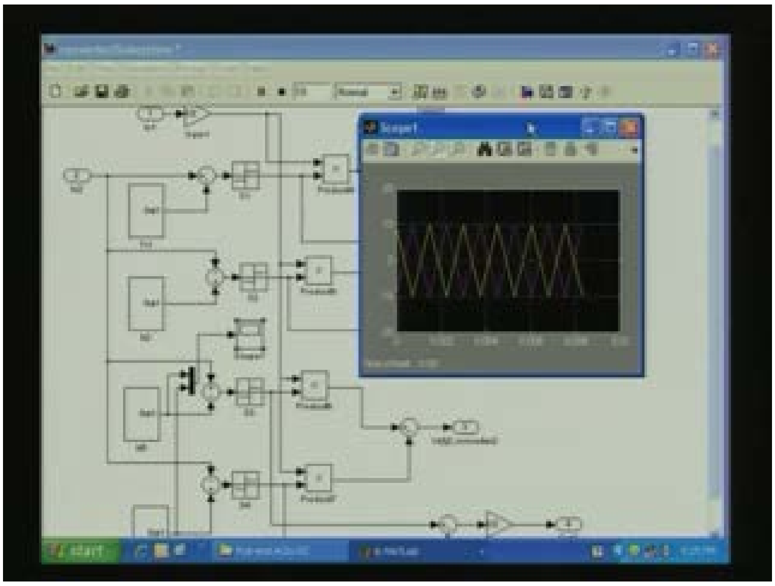

So, why want to do this one? As I told before, these two are 180 degree phase shifted and the switching leg is, logic for this converter is interchanged; for this one, sine is greater than the triangle, top switch is on and here the sine is greater on the triangle, bottom switch is on.

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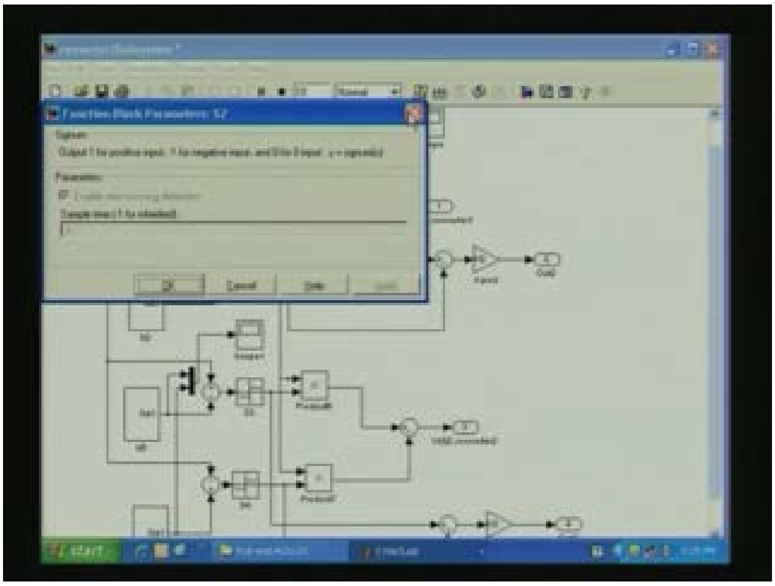

So, this we can take care of this one, output, input relation here by specifying here. Now, by doing this one, all the harmonics at the f_c and side of f_c can be can be suppressed from the converter itself. So, for this converter as well as this converter, f_c and side bands will be absent and the side band at f_c, 2 f_c and its side bands for this converter and the current generated due to that one, due to this converter and this converter are there in opposite. That we saw that the repels are opposite so that that the primary side, it will get suppressed and primary will have the harmonics only at side bands of 4 fc. This simulation result will come to the last stage after going through these all simulation blocks. So, this is clear, this we have understood it.

Now, I will stop this one, then this the converter; so converter will have the switches, here the switches are assumed as ideal, so whenever the sine is greater than immediately top switch is on plus 1 minus 1, then multiplied by V_{dc} by 2, you will get plus V_{dc} by 2 minus V_{dc} by 2. So, here you will get the converter 1 and converter 2 voltages; so slightly shifting we will see. This is the converter 1 output, this is the converter 1 output, this is the converter 2 output, these are the V_r (t) waveforms. Let us see what is this one here?

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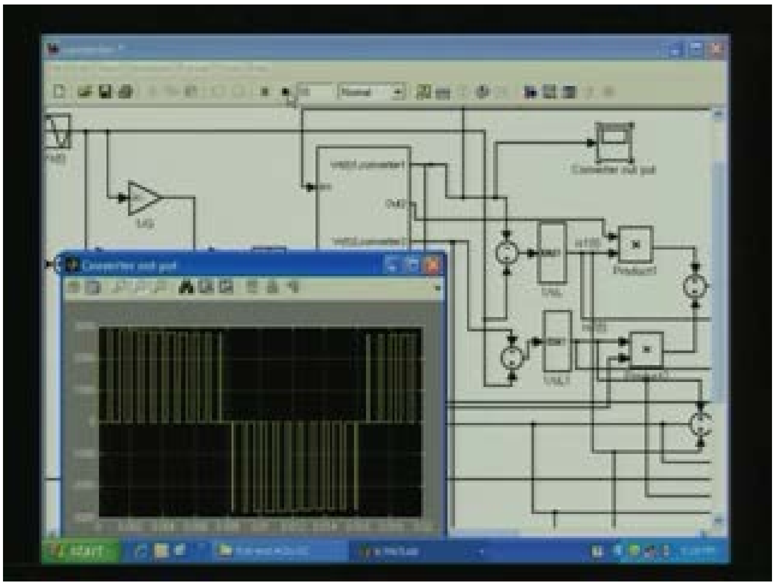

See, this is the converter output waveform here, V_r (t) here, this will show the current waveform. So converter 1, the PWM waveform is like this; it is going to 2800 by 2 tops and minus V_{dc} by 2 it goes and this suddenly you see here, this is due to the capacitor fluctuation. So, we are trying to similar task process possible to actual one.

So, capacitor simulation, we said delta v of plus or minus 5%, so we are doing that one. So now, it is stabilized. So, we have started that one. So, now it is more or less constant. So, now let us see our converter, current waveform for the converter 1. See, how to generate the current waveform here.

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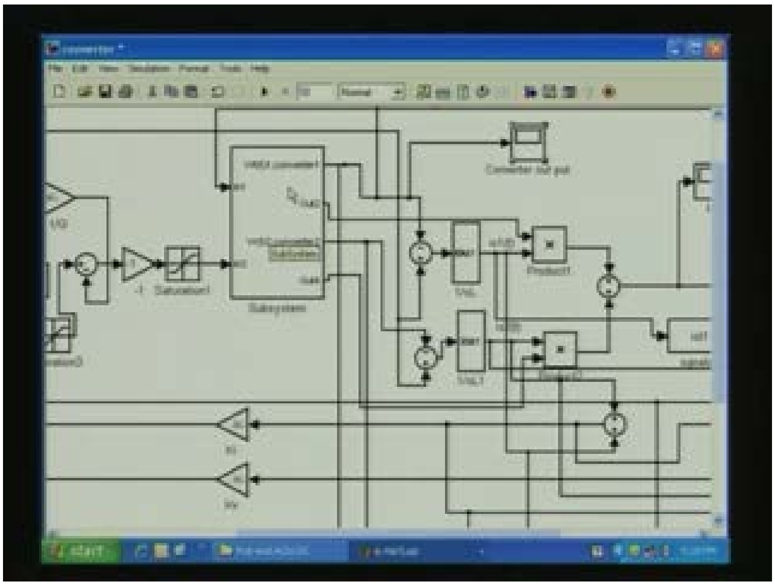

See, current waveform we can generate ((no sound 25:05))

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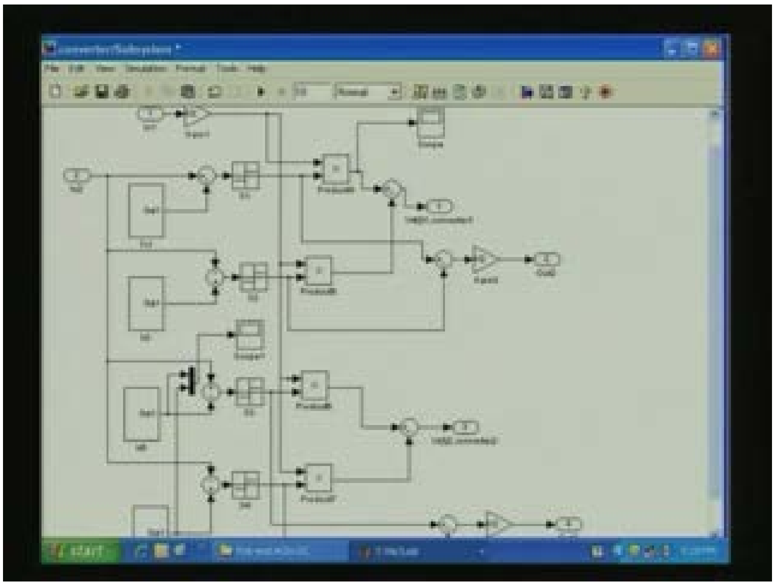

We are getting from the PWM waveform; from the PWM waveforms, plus V_{dc} to minus V_{dc} by 2, 1 by SL integral; here we will get the current waveform, 1 by SL.

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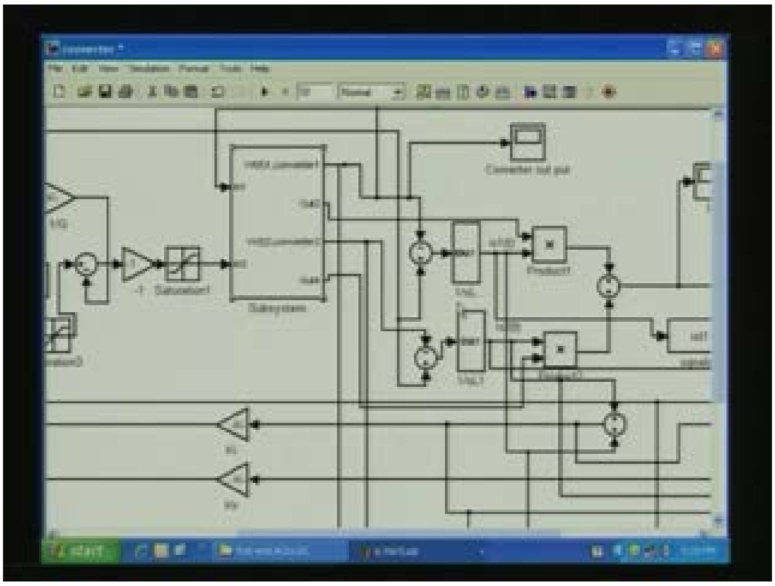

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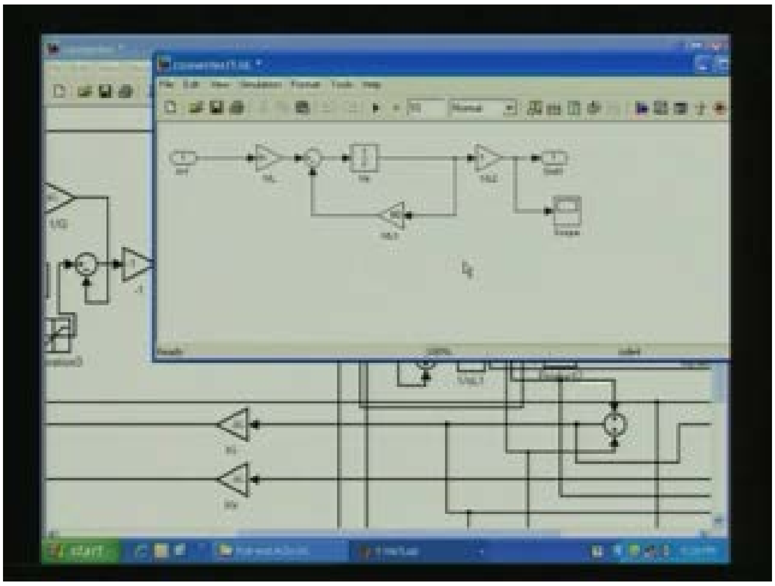

So, this is the one; 1 by SL, this is the one, this way you will it, 1 by SL, 1 by l. So, here is the integral, 1 by L and integral, so while integrating we found that the dc offset error. So, to cancel that one, you get the feedback here. So, this will give the complete motor current. If you see here, simulation, converter current, it will be like this.

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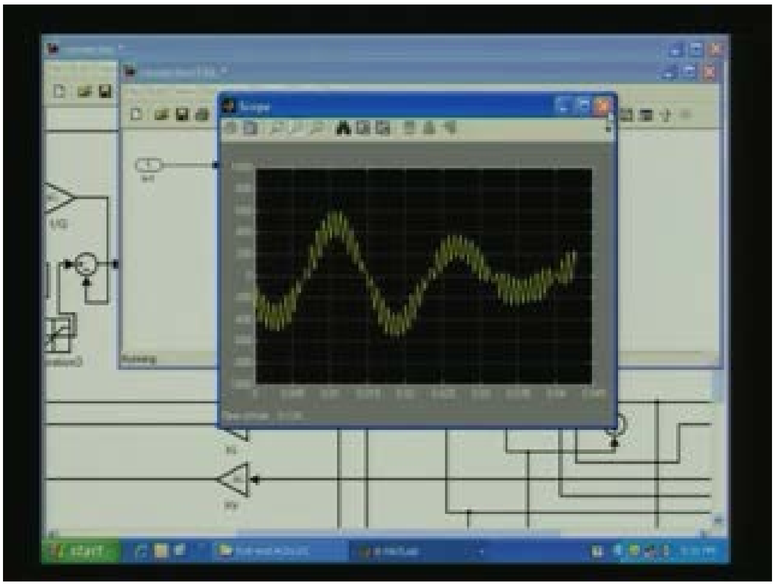

See, this is the converter current, one converter current, goes to the starting. So, it is now, slowly it will stabilise now. So starting, this is your starting only, slowly it will stabilise, the converter current will get stabilised, this is the converter current. Now, the second converter current, second converter current will be, so this converter current is second converter current is here that is for the first converter, this is for the second converter; so the V_{ab}, so Vr, actual Vr minus V_S (t) 1 by SL that is this one, this is the V_S (t) part minus one.

So, that will give 1 by SL. So, here plus or minus that that depends on how you take it; you can take it Vr (t) is equal to V_S (t) plus L into di by dt or the other way, whatever way you can take it but plus or minus is not important here. So, this current comes here. Now, current we got it. So, from this one, how do you find out the converter Id current?

So, if you see here, these converters, there are phase leg and phase b are there. So, these converter current, rectified current comes at the dc side. So, here we will be multiplying by the plus or minus the one output here, plus or minus one output here. So, if you see here, so the converter output; so plus or minus, when the top switch is on, isk will be going to other side. During the negative, when the negative sign is on, if the current is negative, it will go to the reflector on the other side. So, the converter current if you see here, it will be like this.

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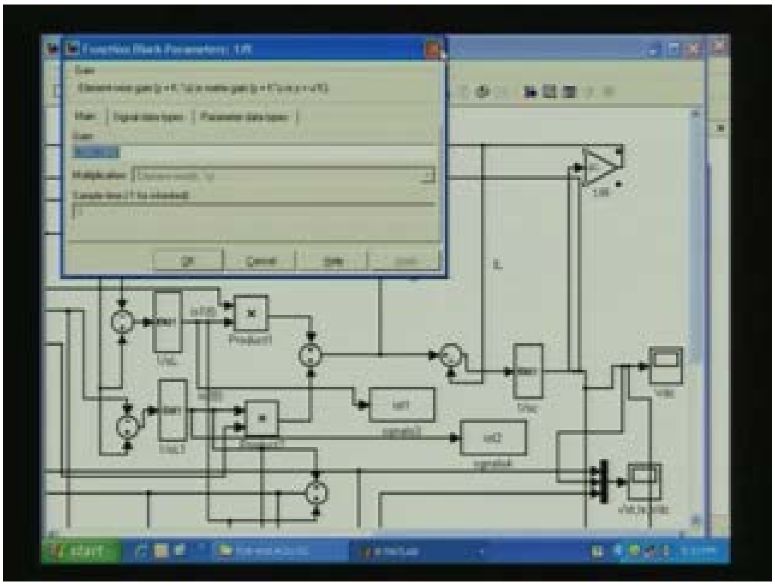

So, this is the converter output current.

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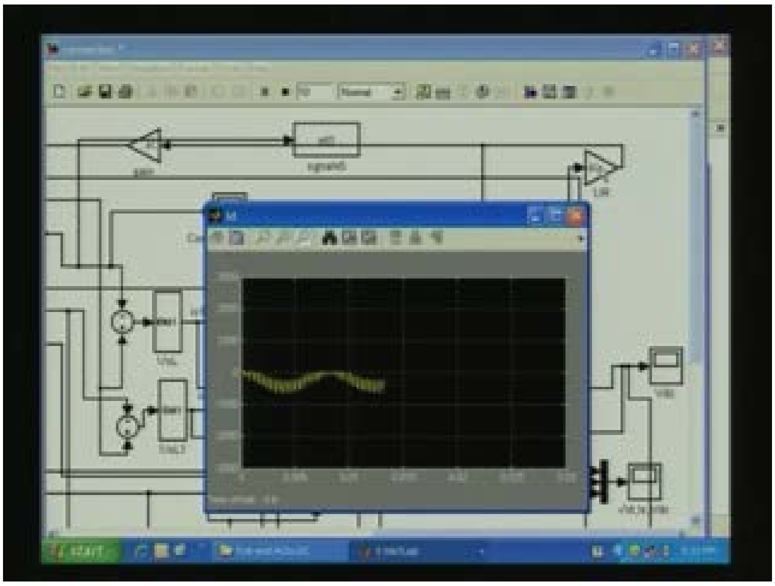

It is going negative ripple, 0 to negative. So, this is because we have made regeneration, load is negative here.

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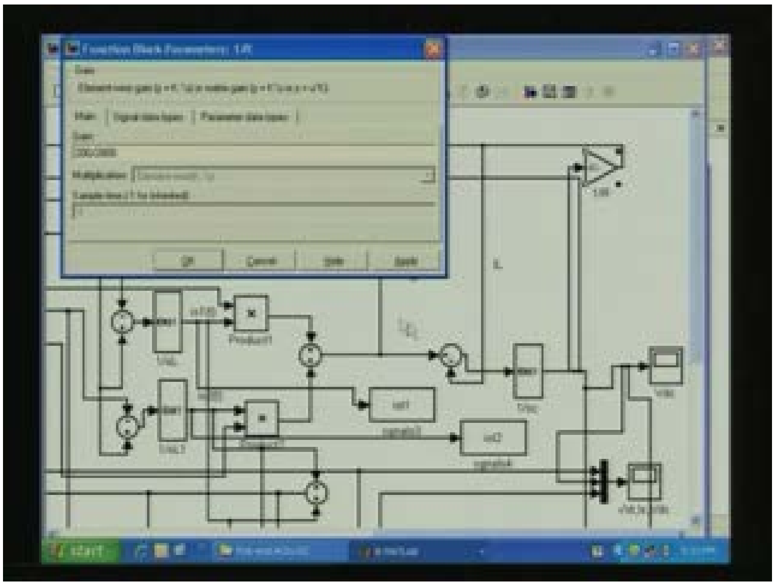

So, load we will make it positive here, then we will get the current flow from ac to dc side. So, now if you see here the Id, see, it is going to the positive side, quickly it changes.

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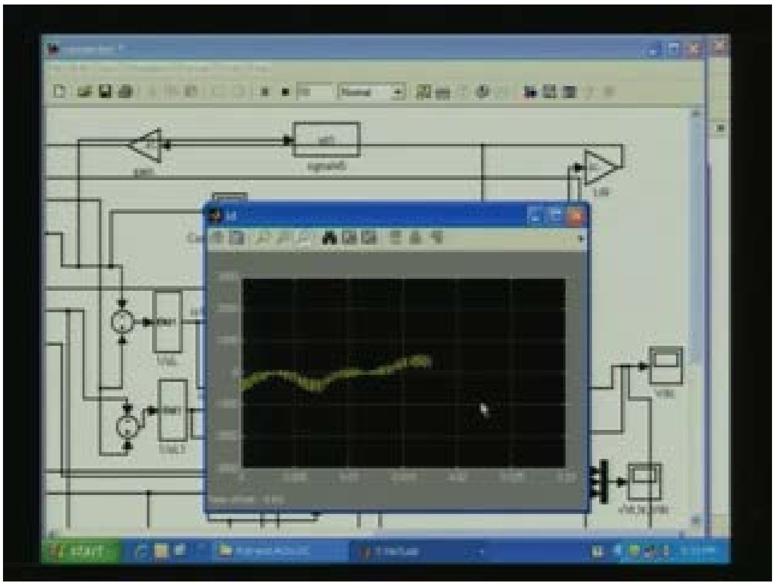

So, its transient is very minimum. So, this is the Id current.

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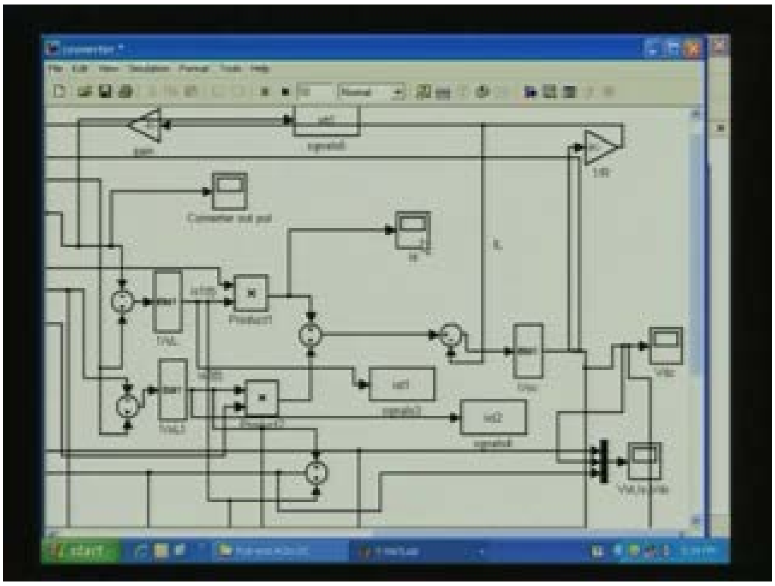

Now, this Id current, these are converter 1, this is converter 2, now we have only shown the total current. If you see, if you want to see the individual current, you can switch off this one and remove this one, individual current we can put it maybe two currents, individual current.

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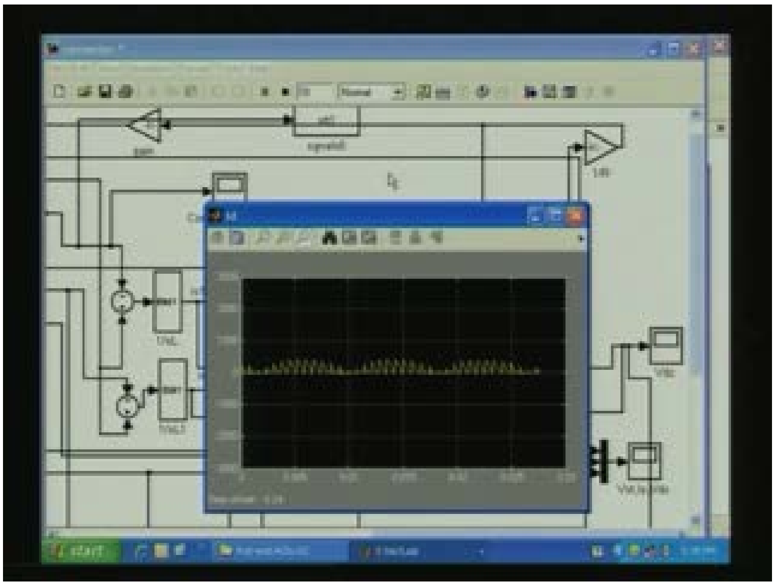

See, this is individual current, so the pulses, it is starting, every time we switch off and shut, its starting. So, the individual current, that is coming towards the Id side that is coming out of the converter, converter if you say dc and the repel will be there, repel will part will go through the capacitor and as I told there is another frequency.

See, this capacitor fluctuation, we have designed with two times the input frequency that is visible here. So, apart from the high frequency repel, there is a two times frequency is there, this current. So, the capacitor repel has to be decided for this two times that we are done be before for this PWM switching frequency; this is for one converter. So, this one, we are giving to 1 by sc, so that will give your capacitor voltage. Then divide by 1 by r that is our resistance. So, this is the block diagram.

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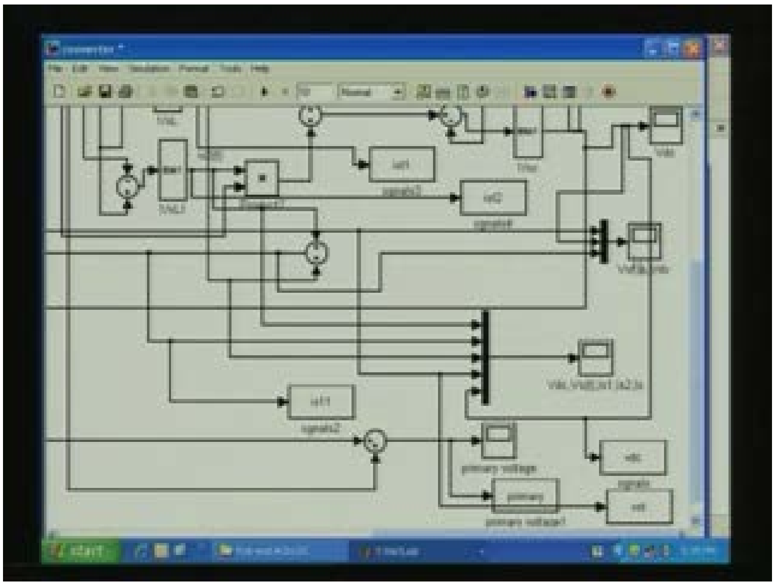

Now, let us see the primary, let us say our V_{S1}, total current V_{dc} and the transformer primary voltage.

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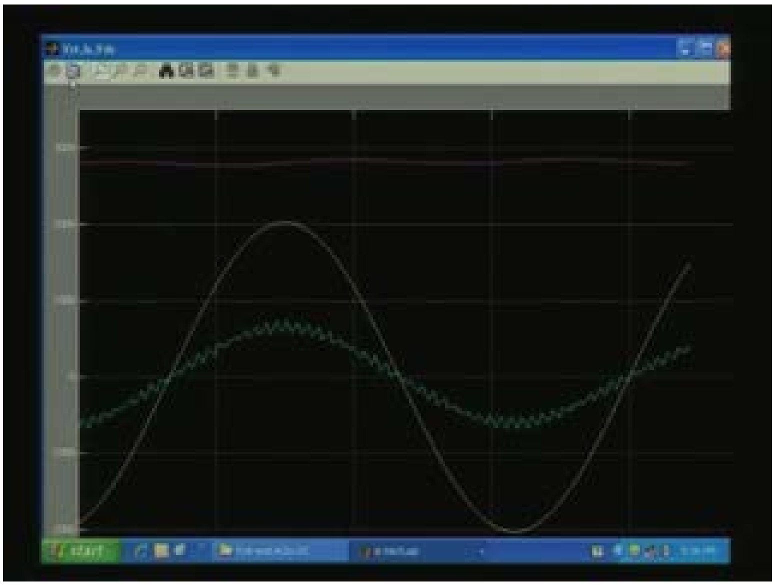

This is the starting and the starting here is assumed, capacitor is not charged that is why heavier transient. So, simulation we can do it. So, this is the transformer primary current, this is the mains voltage and this is the capacitance, dc link capacitor voltage. So, here we can see, it is nearly unity power factor, nearly unity power factor. Now let us see, let us reduce, more number of cycles let us bring it here.

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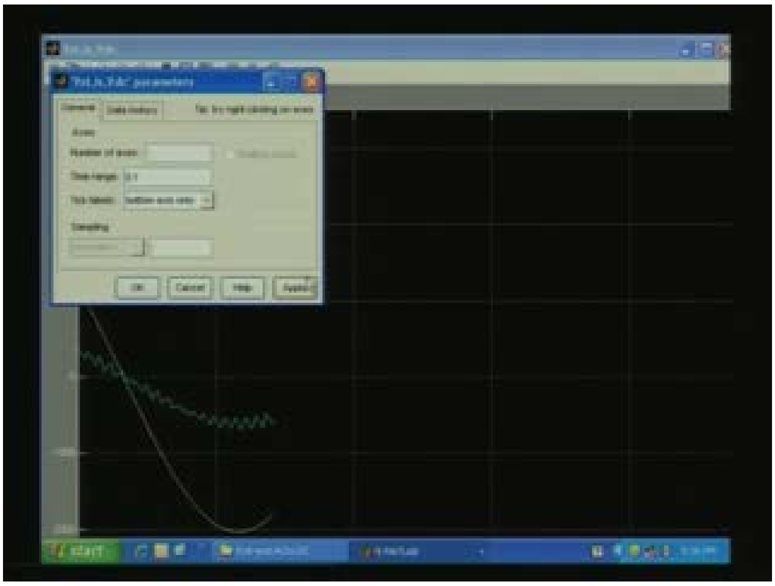

So, that we can, I will make it 0.3; 0.1, I will make it.

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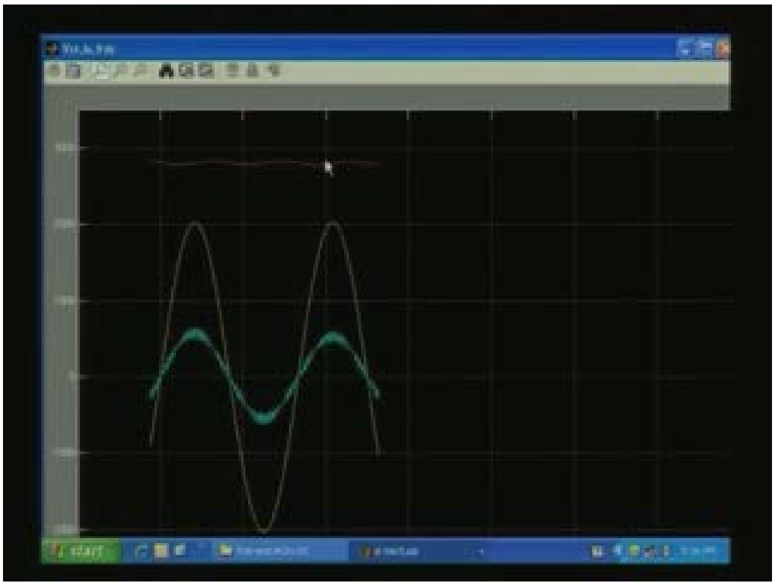

So, more number of cycles you can see here. So, this is capacitor repel is visible here. Now, I want to pause this one, pause and I will suddenly change the load to minus.

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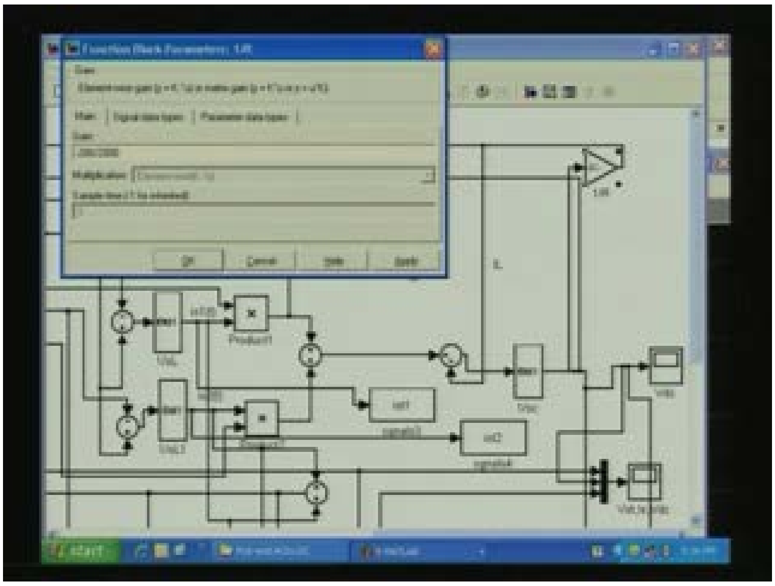

This is minus, applied that is our screen, this is our screen and I say simulation continue.

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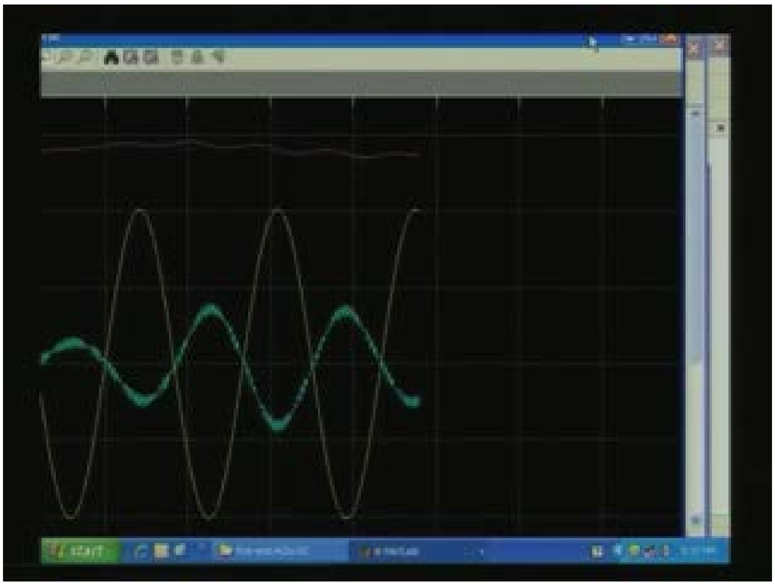

See, immediately power flow is power flow is reversed quickly. So, this is the transient during the power flow reversal. See, quickly power flow is reversed; this is the primary current, this is the primary voltage. Now, let us see the total current and total voltage here that is here that is this one.

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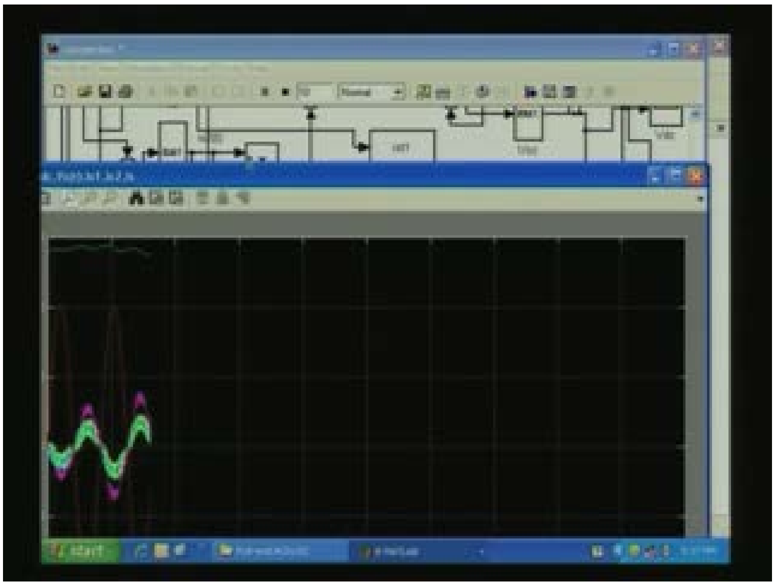

So, this is the one, this is the total current; we can expand and see the repel clearly.

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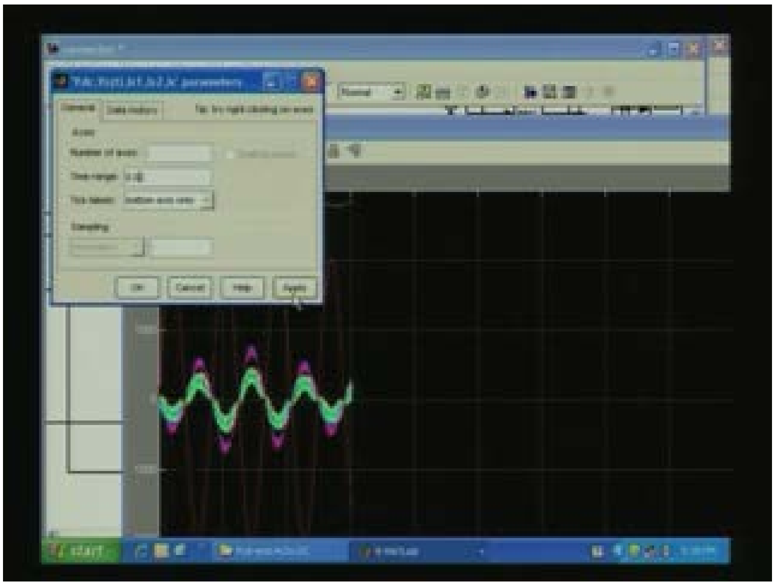

See, during the X axis we can do it. So, we will make it 0 to 10 times, we will increase it; see the repel.

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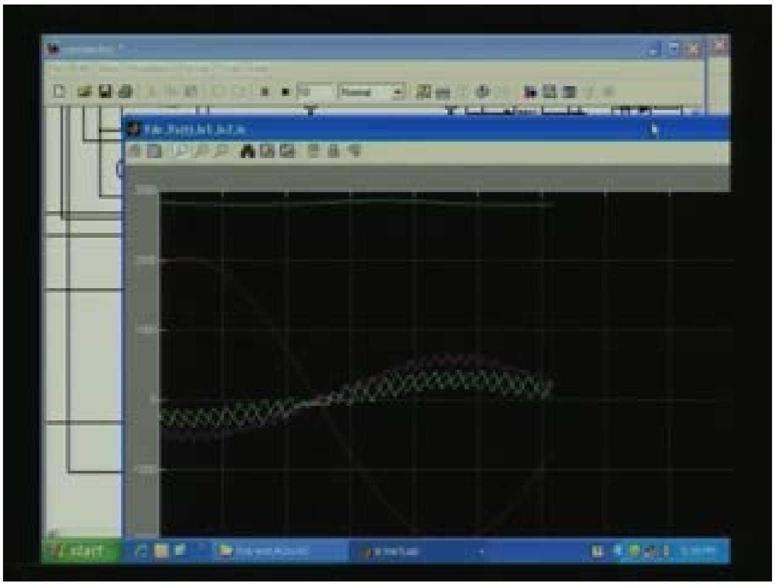

As i told, see because this opposition from the two converters, that makes the harmonics at the second f_c, side bands of second f_c get suppressed at the primary side. So, the primary repel will be much less, you can see here; these are the individual converter currents. Now, let us see again here, increase the scale here and see.

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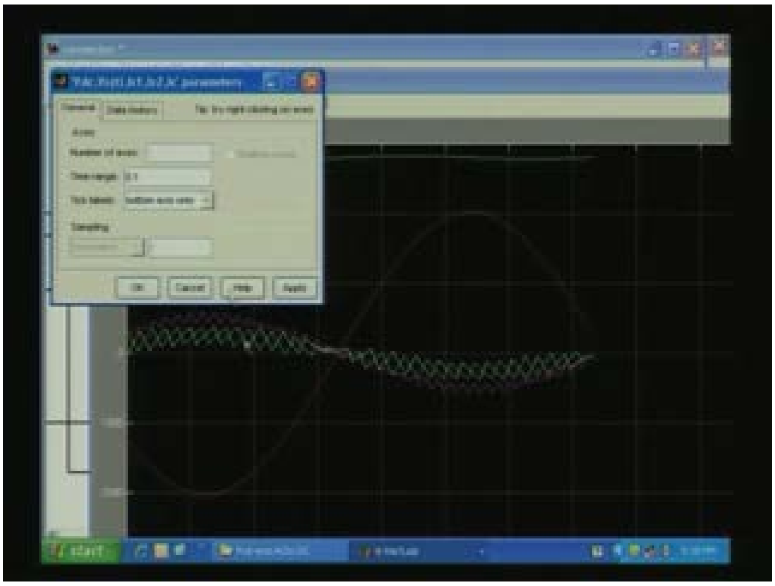

The current reversal we can see it here; instead of 0.02, I will make 0.1 here.

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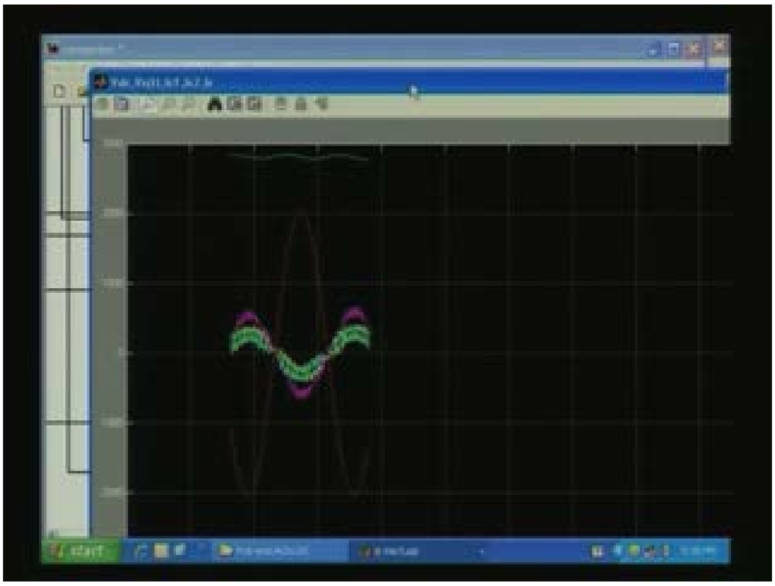

So, this is the one. Now again, load, sudden load change; I want to forward power flow. So, I will pause this one simulation, pause it and I will go to this one, change the load to positive.

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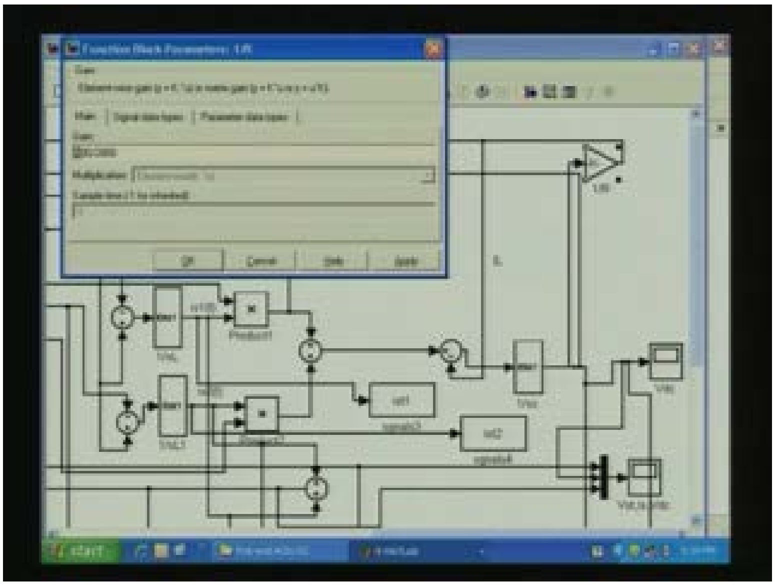

That is the way we are simulating the forward power flow and the reverse power flow here and simulation continue. Let us see.

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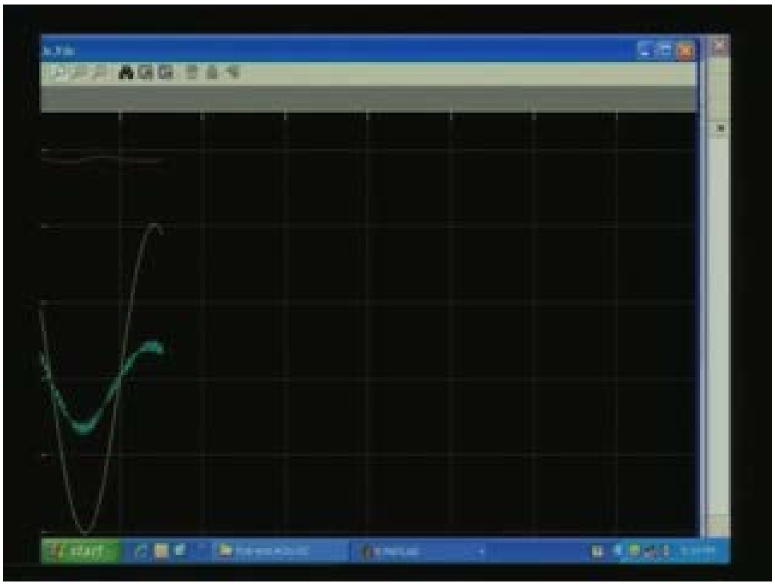

See, it quickly changes, very fast change with nearly unity power factor. Previously, it was reverse power flow, now it is forward power flow. See, quickly it changed, this is the one.

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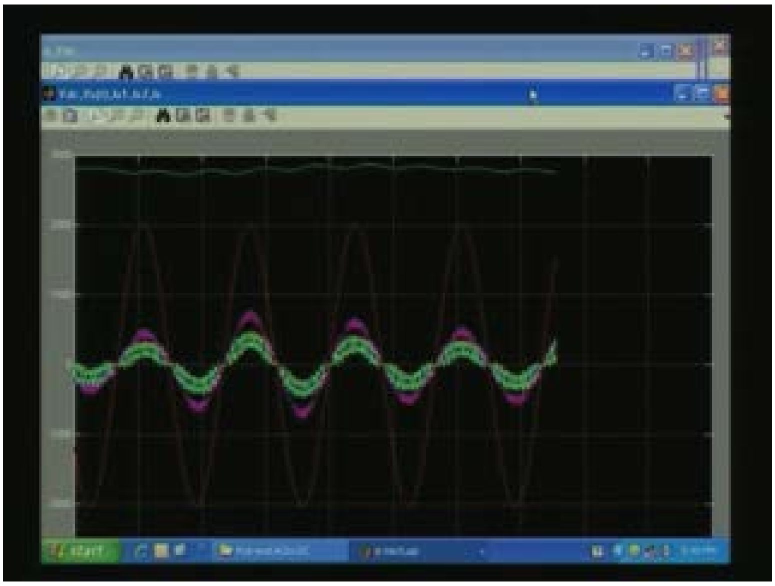

See, here also if you see here, see it has quickly changed. Here, two converter currents, we showed. So, this way, we can, before fabricating, before final design of the converter, controller we can tune it like this. So, our assumption and theories are correct.

Now, let us see the effective waveforms here it is coming out, whatever we predicted is coming. So, we will again go back to our design quickly and come to our simulation result.

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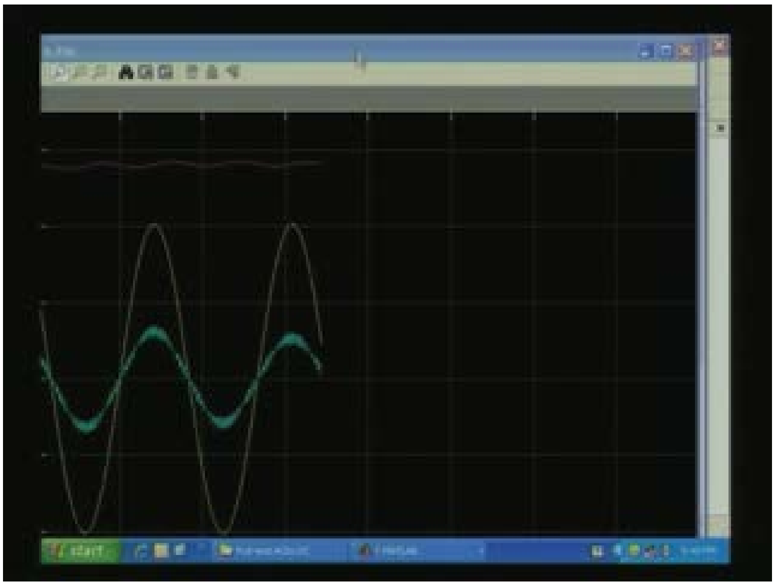

So, I have shown this one to get a feeling for you that so all the design with engineer approximation using the correct engineering approximation, we can model the system, find out the transfer function and from the transfer function, we can appropriate controlled design we can initiate and we can arrive at the controller. Once that controller parameter is also designed, we can go for a simulation study and we can use a various control blocks here and we use the simulation study here.

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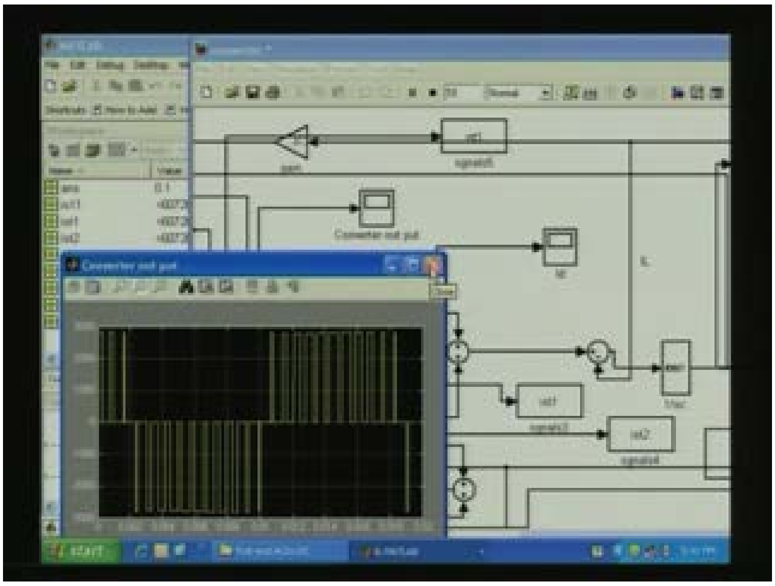

So, this is the converter waveform. When the converter is positive, the current will be going through the Id; the negative side, it is the reflected one it will come. So, this is by multiplying the plus part and minus part, plus 1 and minus 1 by the i_S (t) current, the reflector Vdc rectified current, we can get it. So, that is the Id; that Id, i showed you that is this one, this Id.

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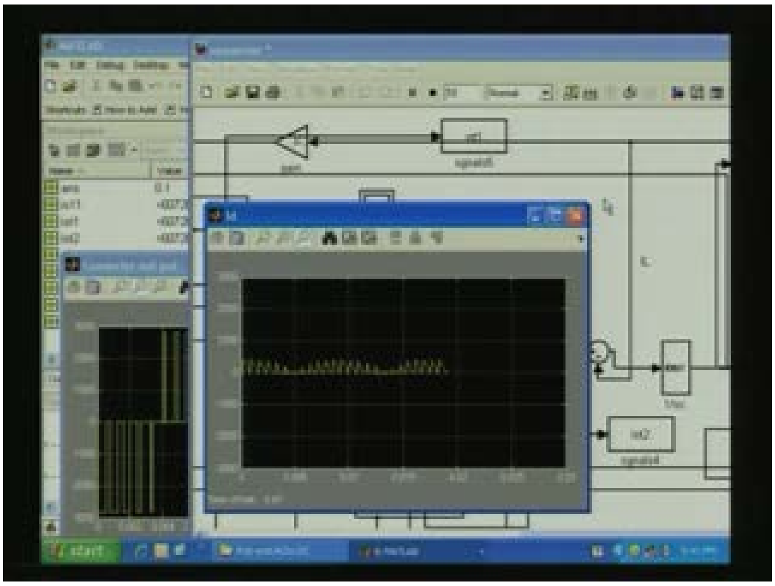

It has a two times the main frequency component is there. So, your capacitor has to be designed for that one. So, we have designed the capacitor, capacitor repel also we have seen; now let us see, again quickly we go back to our fftb; both is coming.

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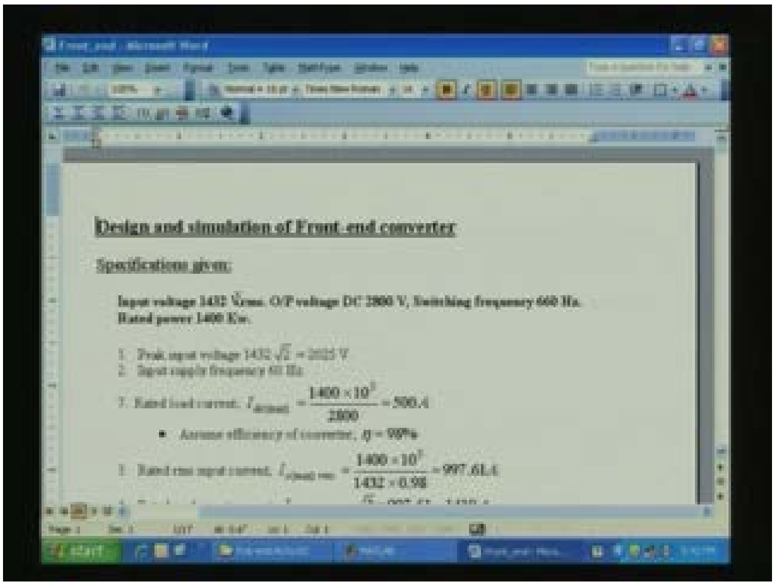

So, design of the simulation front end converter; we said, input voltage is equal to 1432 Vrms last class we have seen and output dc at 2800 volts and the switching frequency that is the triangle frequency 60 into 11 times. Now, peak input voltage that is 2025 voltage, input frequency is 60 hertz, rated load current 500 amperes, assumed efficiency of 98 %; rated rms input current we can find out, equating the input power to the output power with efficiency. So, this is the input current we can get. Our rated peak current is this much.

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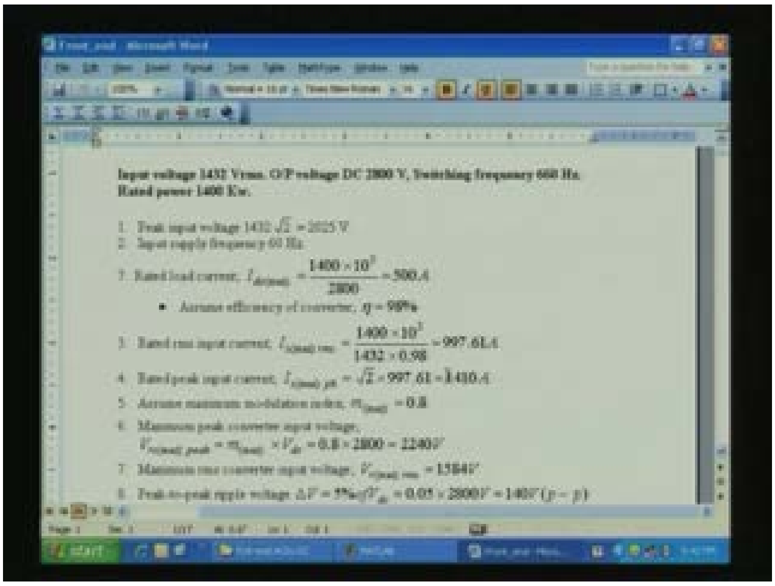

Assumed and modulation index, we set 0.8, we will not go to the peak value of that. Our modulating is Vr (t); we do not want to the peak value of the triangle waveform to avoid in practical case, to avoid another switching pulses. So, modulation touch will only get 0.8. So, that means if 2800 volts is our output dc voltage, our Vr (t) that is our Vab reference maximum we can go upto 0.8, 22 2240.

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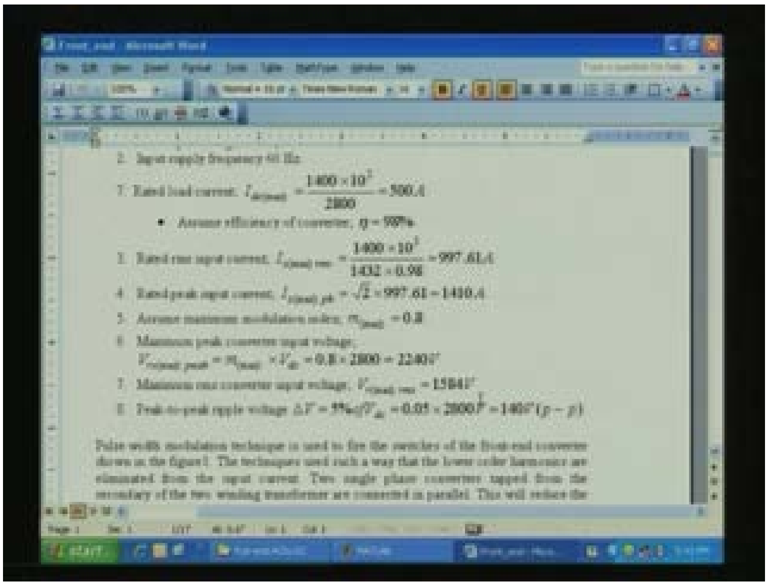

So, that with controller gain, we have limited that one. So, maximum rms converter input voltage, then peak repel delta v of 5%, that we found 140 volts. So, this is the thing.

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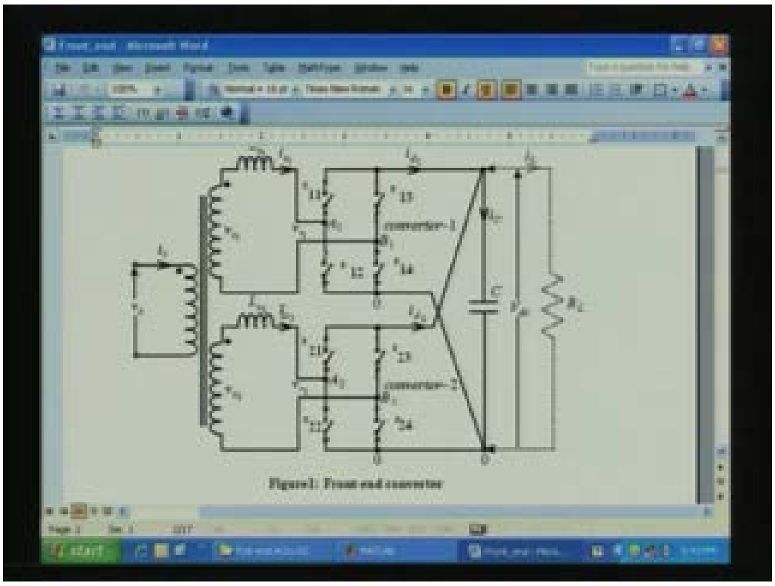

This is the converter we have used, this is the current, this is the current. See, this current is the current coming here. The one; how to get this one Id? When this switch is on, this current will come here. Then these two switches are on, whatever the current coming to this left that is if your taking this current, the negative of that one will go here that is why we have taken the Vab, this one positive side, Vab positive one, negative one multiplied by the current value that is we are show showing the rectification; we will get the idrm Id current here that is how 2 Id current we have stimulated here, then this is the capacitor.

Then, also we found out that for this limb, A limb and B limb of converter 1, the triangle waveform is 180 degree phase shifted and we are using the same sign wave but the switching logic for this one is ((Ulta -reversed)) that is whenever sine is greater than triangle when we are switching on this one here with the 180 degree phase shifted triangle, we are switching on this one. So, for the fundamental to get added and all the carrier frequency at f_c and its side bands, get suppressed cancel. This is true here also. So, this current waveform and this current waveform will have the harmonics at 2 times the side bands 2 f_c and it appears at the side bands of 2 times the carrier frequency.

Now, by 90 degree phase shifted between the triangle waveform of this one and this one, and this one and this one: two times, so 2 into 90, approximately 2 into 9, 180 degree. So here, these currents, the flux generated by these two currents get cancelled and it will not reflect here. So, the transformer primary current will get only the harmonics at 4 f_c and its side bands; this, from the simulation study we have found that one.

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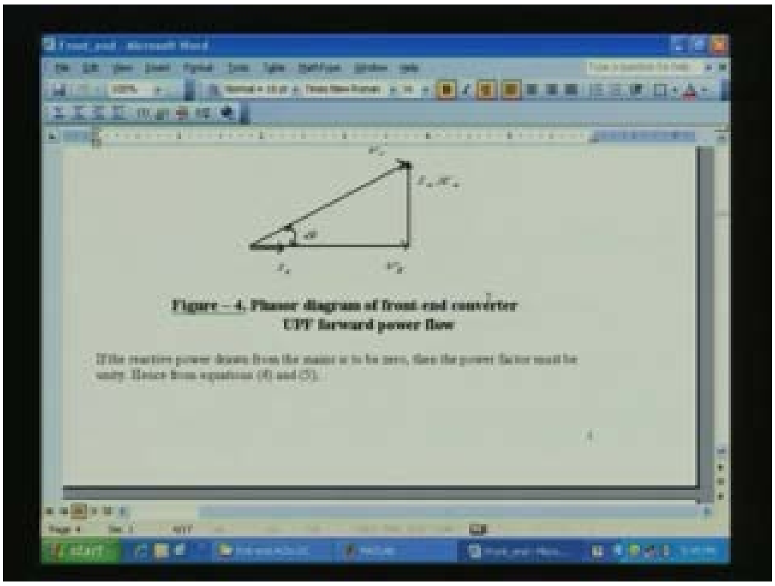

So now, these are the current designs, see the unity power factor, how to do that one so that we will generate the i_s in phase with Vs, that we have done and we have given a slight phase lead to take care of the converter delay because we are doing the sinusoidal currents here.

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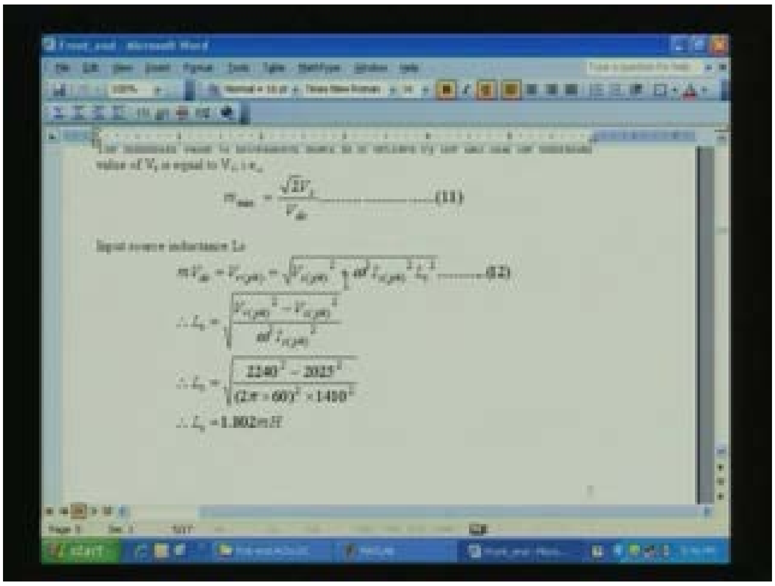

Now, how to design the inductance? So, this is very easy. From this equation, Vs is equal to Vs (t), Vs (t) plus the L di by dt is equal to Vr. So, from this equation, Vr is the root that is it is a triangle, right angled triangle. From there, we can find out Vr, L we got approximately this value here.

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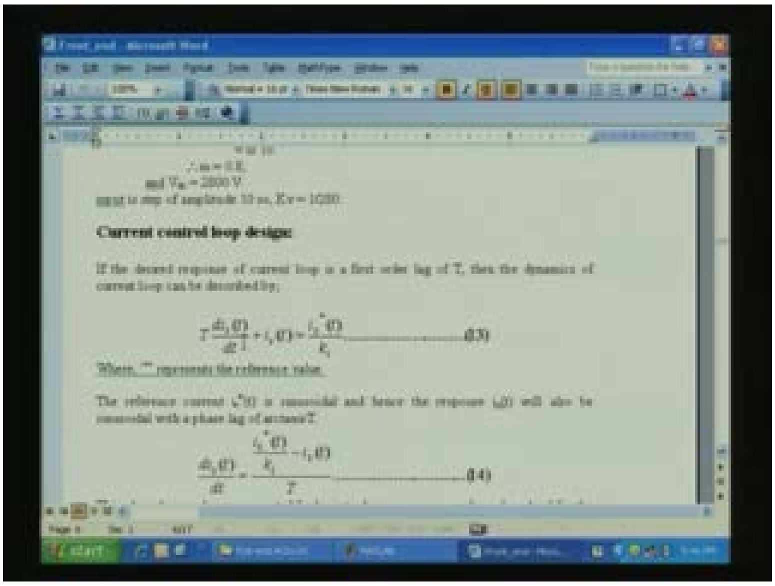

Then converter gain G into 1 plus STr, triangle we found for the 60 times, what is the time period, gain for a 10 volts, it is 280, we can give that G.

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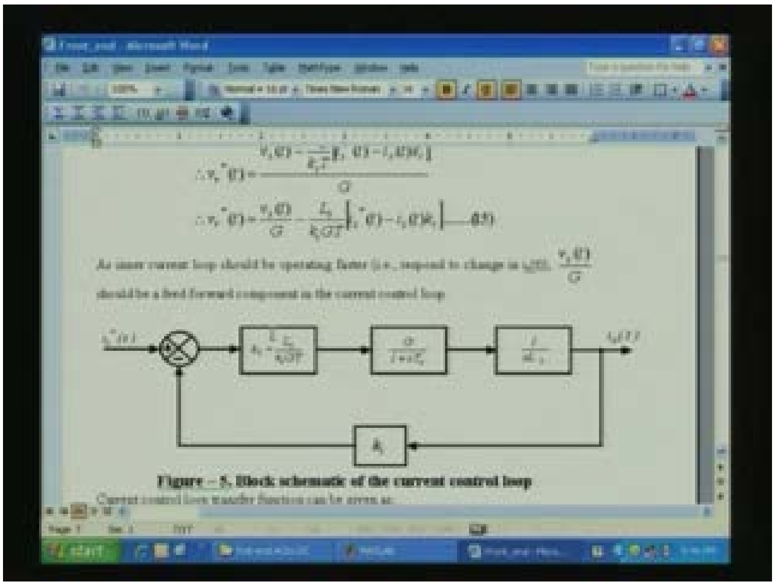

Then the current loop design; for a first order lag equating that thing, we got the current, we require only a simple gain loop here and the first order lag here.

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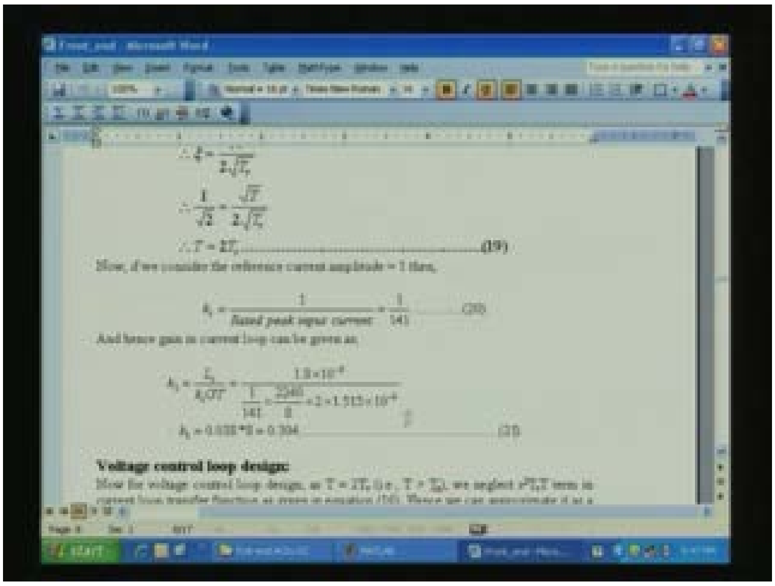

So, we found the current response is something like this and assuming … factor from the control system design, from the standard text book detail, zeta is equal to 0.707, we can design or we can find out the T. So, T is equal to, that T initially we put it as a first order lag we want, the whole system we refer it to the first order lag that is the equation. So, T we found, it is equal to 2 Tr with this …, Tr is our triangle period. Then Ki, current line, that gain that gain we have found out.

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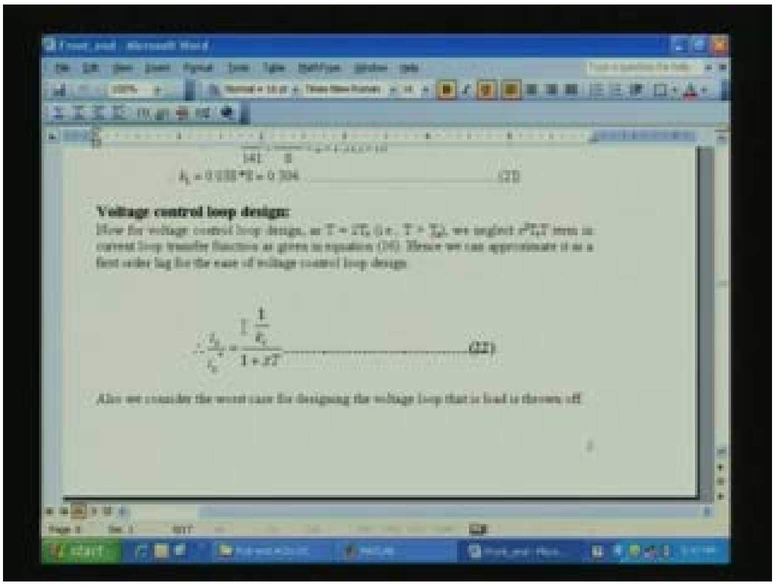

Then these currents loop; see this current loop is coming inside a voltage loop, the dynamics of the voltage loop is much slower than this one. So, all the S square terms in the current loop we can, this part, we neglect it. Then when we are considering this loop within the voltage loop and the current transfer function, we approximate like this that is here. Then, we this one insert into the voltage loop and would put PI controller.

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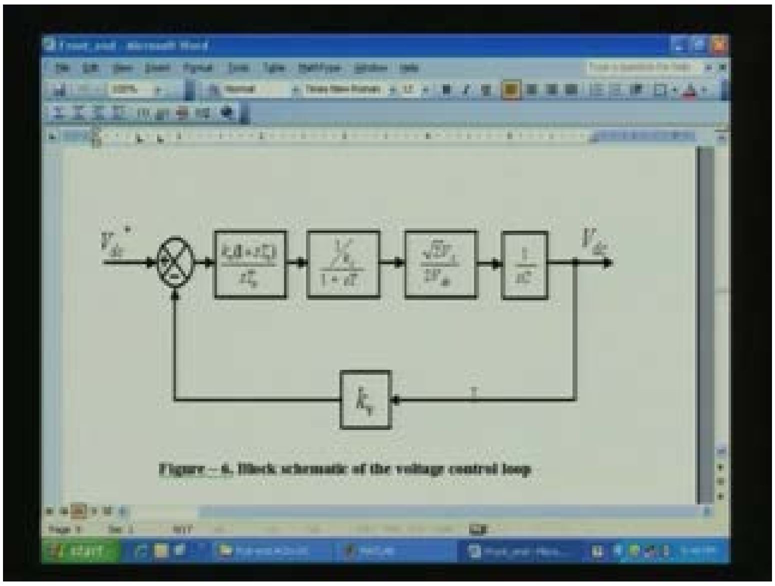

So, this is the final loop, once again I will do it; this is the reference, this is the feedback. So, final loop, we get it. So here, what you have to find out? The Kn and the Tn.

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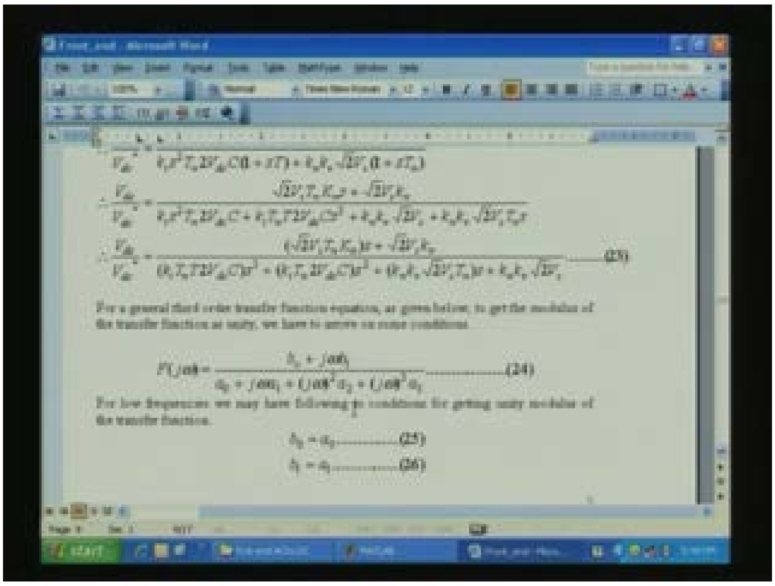

Then we use the principle of modulus hugging, closely transfer function. See, the purpose of this close loop is input should follow the output as fast as possible. So, for wide frequency range, the ratio, the modulus of the output by input should be equal to 1. So, how we can choose Kn and Tn such that for wide frequency range, the modulus will be equal to 1?

So, we studied that one and we got this equation and we found this is third order system. So, for order systems, so b_0 should be a_0 and b_1 should be a_1, one condition; so low frequency, this will be the one.

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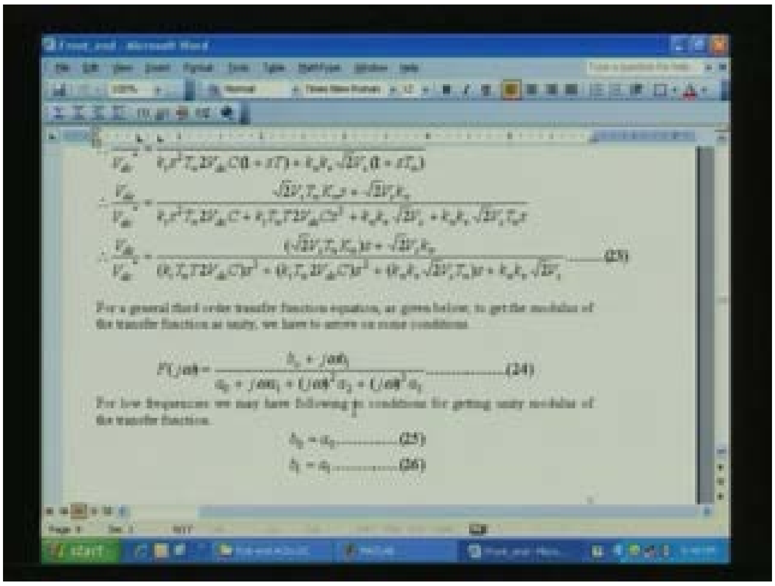

And, for higher frequency, we found out the modulus and got this equation should be 0.

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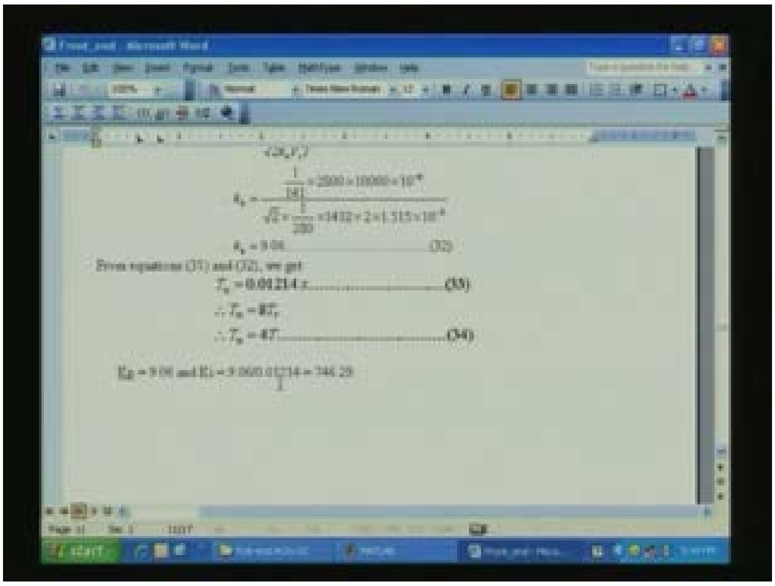

So, final transfer function with modulus or with optimisation approach, what we have adopted, it will be like this; from this one, we found out the gains Kn and Tn equating that one. This is the one we are using in our blocks; the final block is like this.

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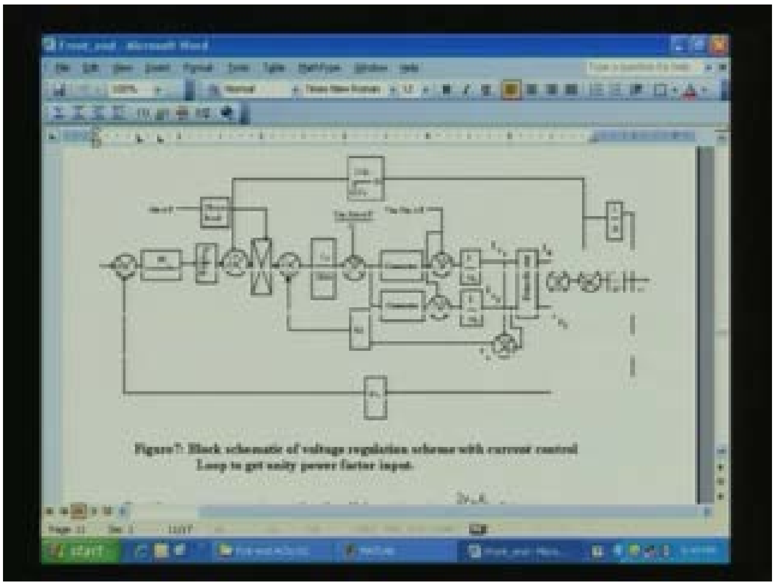

So, this is the one we have, this block we have used for simulation. So, this is the reference, this is the feedback, this is the voltage gain, then the PI controller we have selected the value and the PI controller has a limit plus or minus 10, then this is the feed forward resistance. If you send the load current, we can give a feed forward here such that any time load changes, it should not the current loop should not act or need not act through the capacitor the output voltage loop because any change in, if this is feed forward is not there, need not be or if feed forward loop is not there, it reflects on the capacitor voltage and the correct reference comes through this one otherwise quickly it can act through this way.

Then we are multiplying this one with current reference and a phase lead; current reference comes, then the current feedback. So, here two converters are there; converter 1, converter 2 and each converter should supply equal power and equal currents. So, both currents we can add and we can take the total current. So, we do not require two different current loop voltage loops.

So, one current loop and the corresponding references, we can feed it to the converter. So, this is the converter 1 and converter 2. So, converter minus our input sign voltage 1 by SL will give our current waveform. This current waveform rectified through the mains, it will appear as the Id_1, Id_1 we found it has the repel content as well as two times the input frequency. This current one charged with 1 by SC, you will get the output voltage and this output voltage, we will be feeding here; this is the block we have simulated here. So, that is the MATLAB block we have simulated previously.

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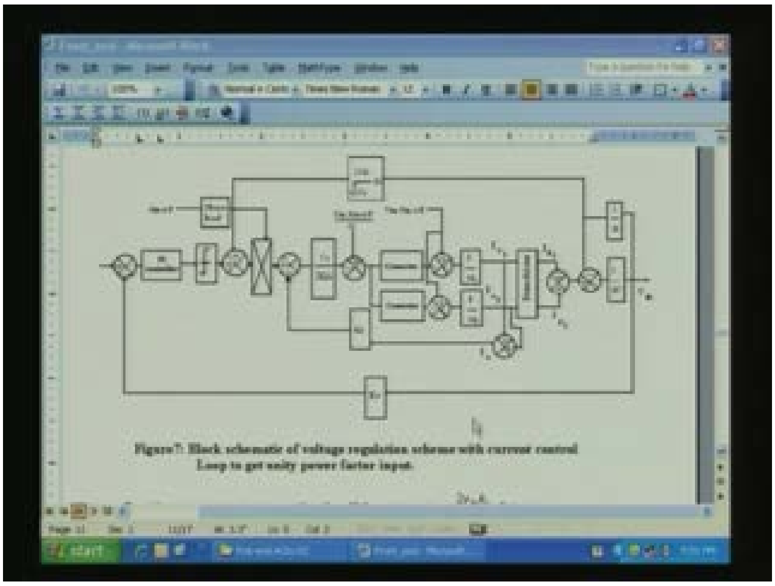

Now, how to find out the capacitor value delta V? Again from, two times the input frequency. So, that is why we got this value, we got approximately 5000 and we are using a standard value of 10,000 for our simulation.

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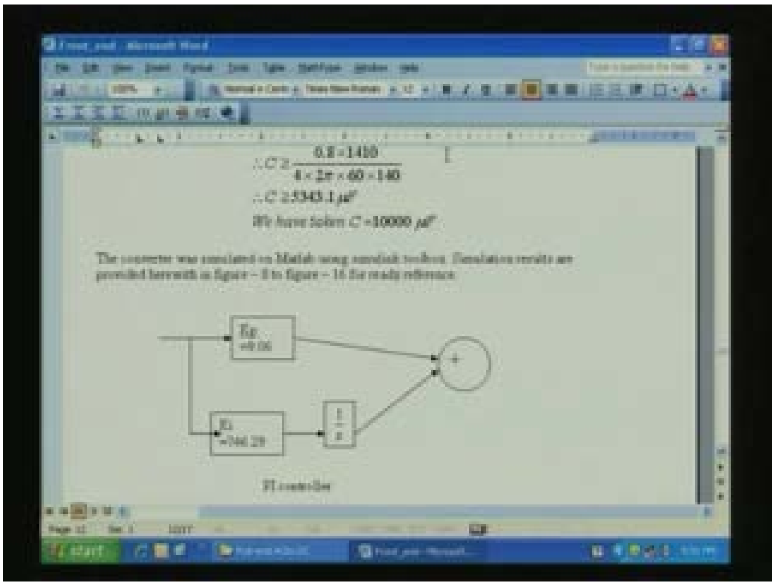

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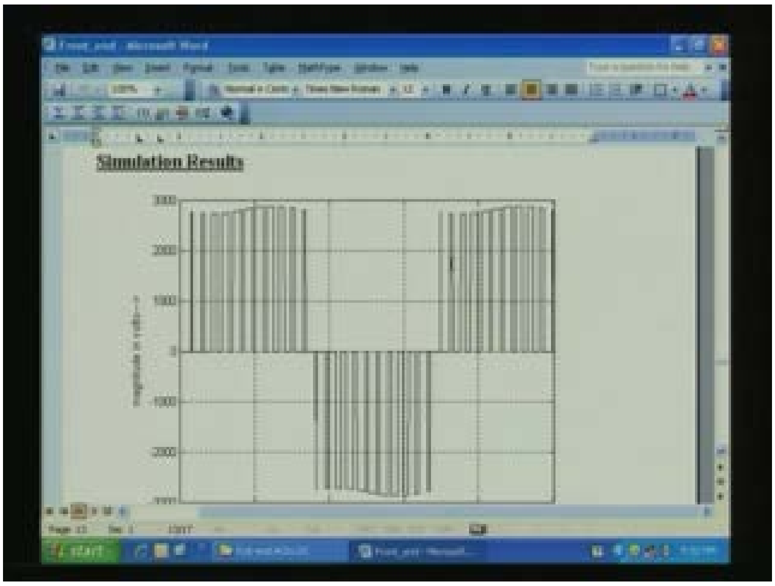

Then the simulation result; see this is the one converter waveform, this is the simulation result that we have seen now. So, this is the converter voltage. If you see here, this is the repel due to the capacitor, capacitor repel two times the mains frequency. So, we can see that one; this frequency is not based on our carrier frequency PWM frequency, it is depends on the input mains frequency, capacitor voltage.

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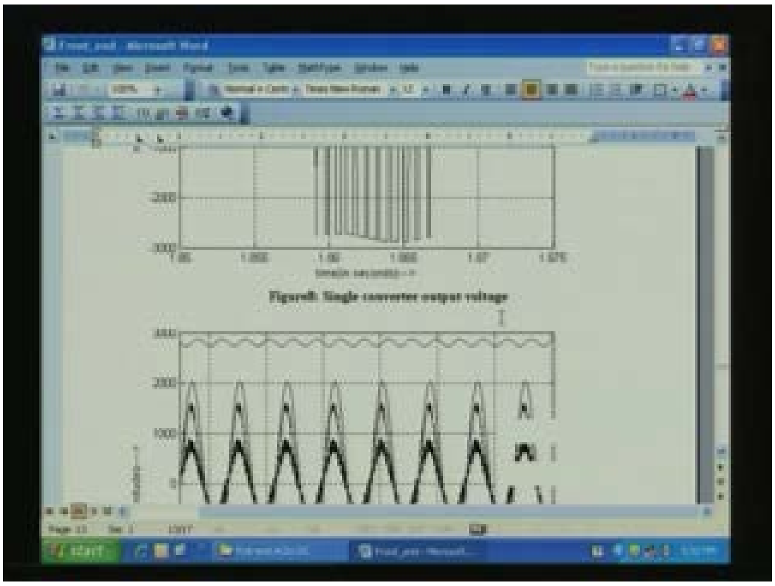

And see, the large scale, the capacitor, delta V 5% of our 2800 voltage.

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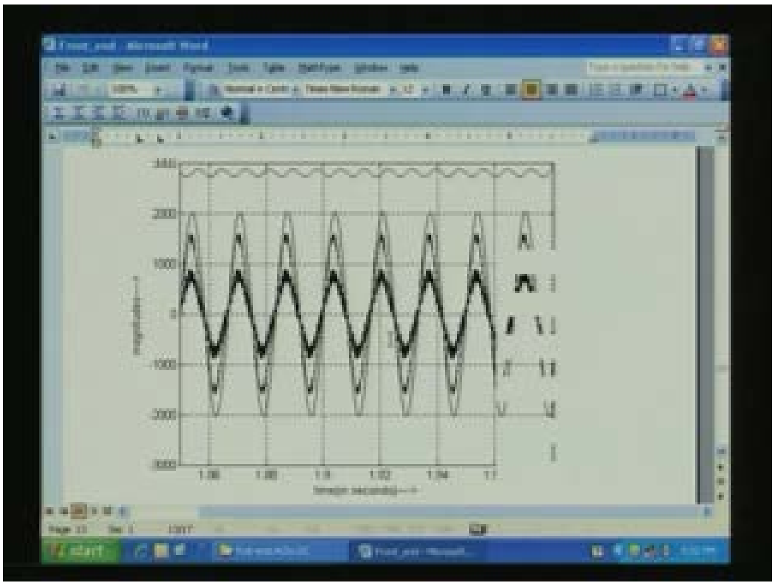

So, this is our capacitor voltage and these are the, this is the mains, this is the main waveform what is shown here and inside this one is the large one is the current waveform, primary current and these two are the two converter current waveform. So, this is power flow from the source to the load with a unity power factor.

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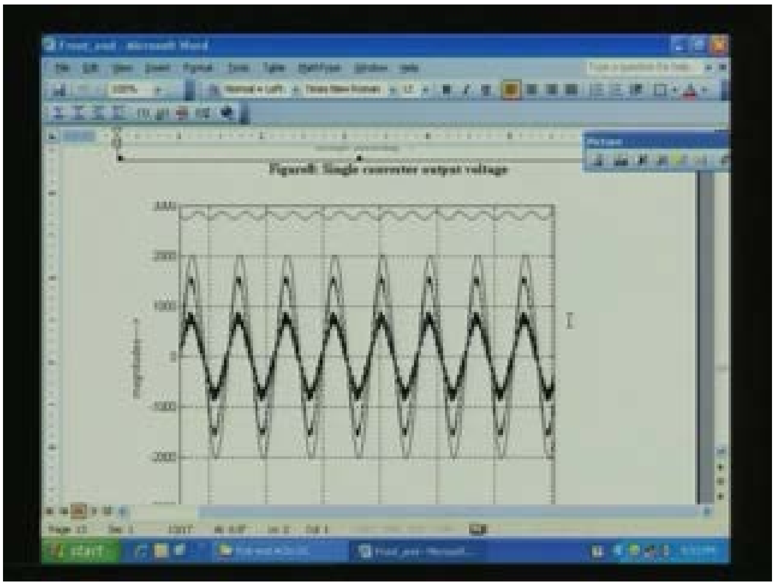

So, clear waveform is visible here.

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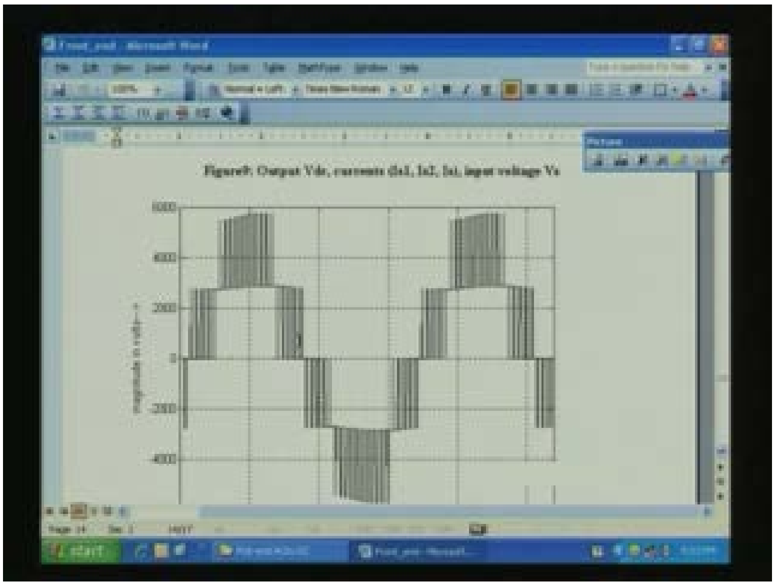

Now, this is, see you have two converter waveforms. If you observe the waveform here, measure the waveform and the converter side that is your transformer primary, here, this waveform will be the reflected waveform from the two secondaries.

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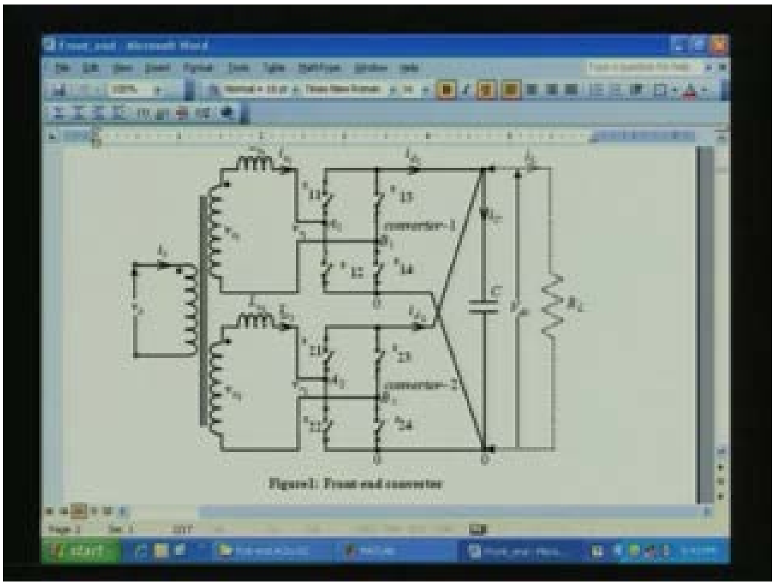

So, what we do to get a feel for the transformer? And, second harmonic will not be here. Harmonic at the harmonics at the second f_c, 2 f_c side bands will not be there. So, if you see here, the primary side voltage will be, will be like this.

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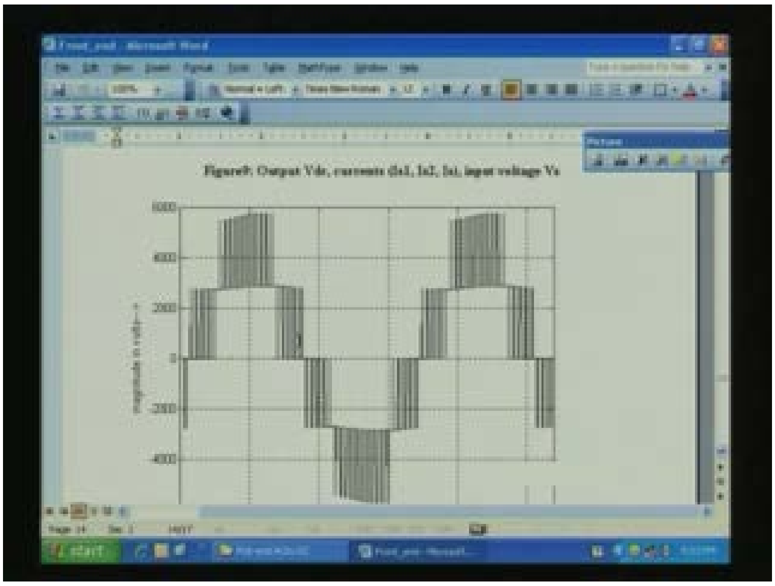

This is the primary side voltage.

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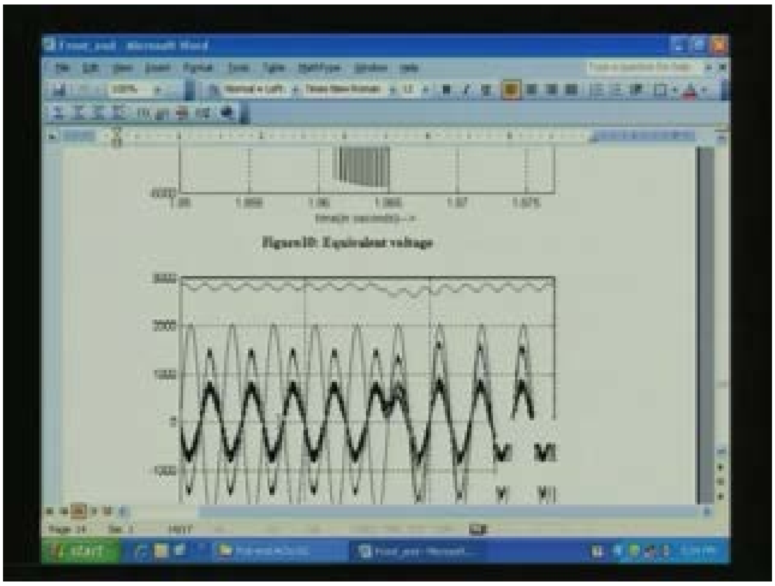

Now again, now we are suddenly quickly we are doing the power flow reversal is there. So here, quickly we paused the waveform, made the resistance negative and how to, see, but the natural practice this much will not be there but we want to show that dynamics is very fast here. So, our controller shows also accuracy of our controller design.

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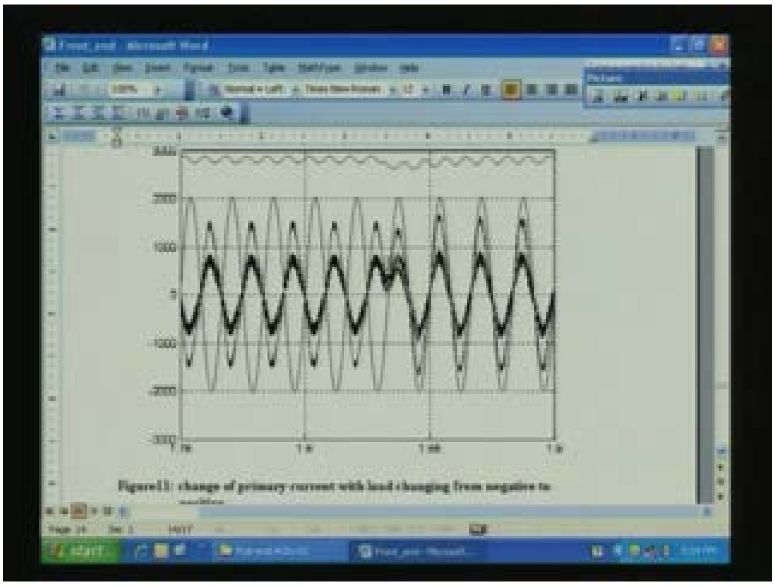

See, quickly power flow reverses. So, power flow changes, so there is a slight repel from the voltage waveform so that transient quickly settles within two cycles, one cycle or two cycles it settles here; it is visible there. So, this also shows our controlled designer, accuracy; our approach is correct.

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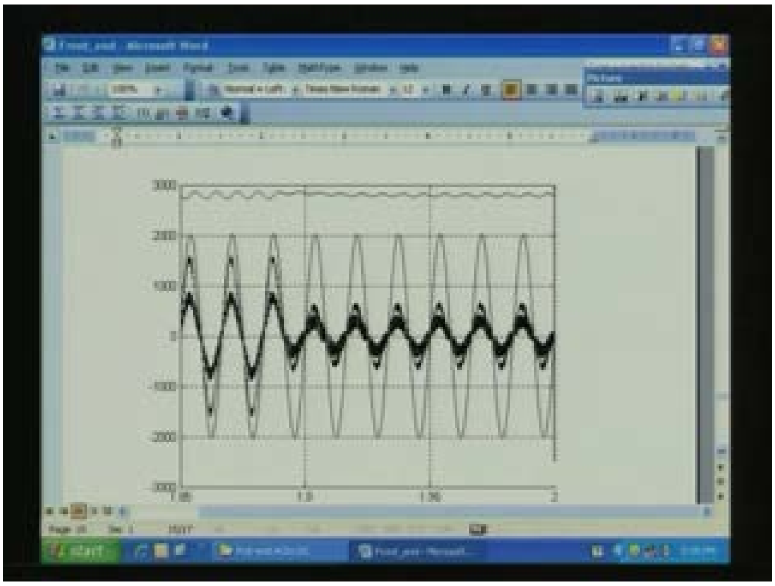

Now, the simulation I could not show because it was not quickly, suddenly removing the load. So here, I suddenly removed the load. If you see here, when the load is high, repel is high. So, maximum repel we are limiting within plus or minus 5%. Now, the load current is slightly reduced. So, quickly changes. So, capacitors repel also reduced but there is transient that quickly adjust, the transient is very less. This also shows during transient conditions not only power forward for reverse flow our controller design approach is correct. So, sudden change in load that is also correct.

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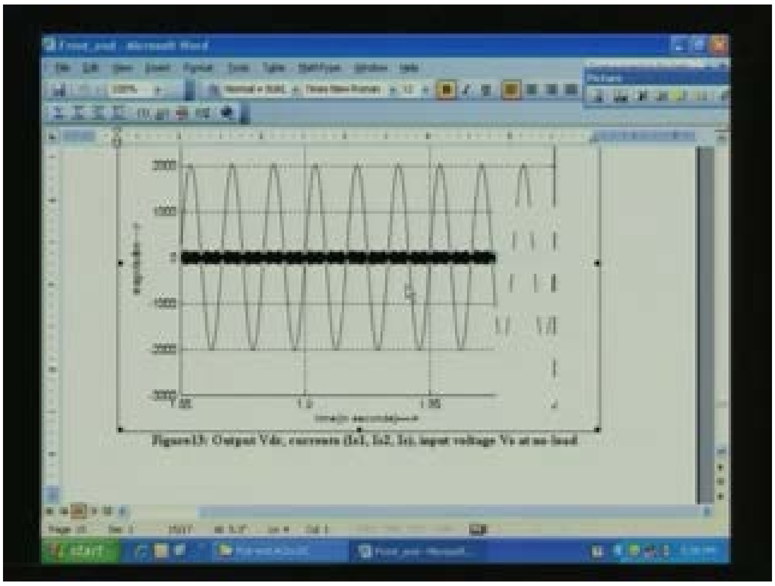

Then no load operation, this one shows. This may be no load operation, we have transformer primary current will be there, magnetising current. So, this is only what we show is or we have the … very no loads operation. Now, let us go to the FFT.

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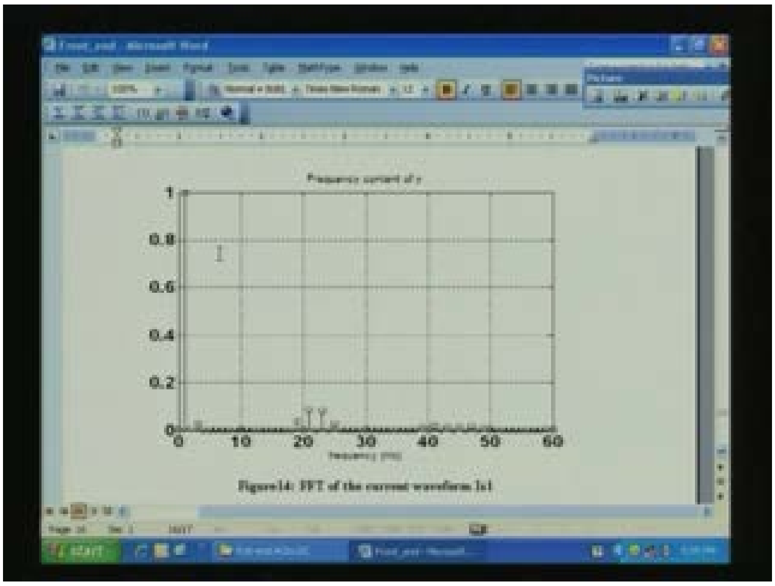

See, FFT of the current waveform I_{S1} converter 1, if you see, you have the fundamental and the harmonics, 11 times, 11 times it is somewhere here that is the kind of figure; there all the harmonics are suppressed. Then the next higher order harmonics happens at this side; 2 f_c and the side bands and 3 f_c also it is cancelled, then 4 f_c it happens; this is for converter 1.

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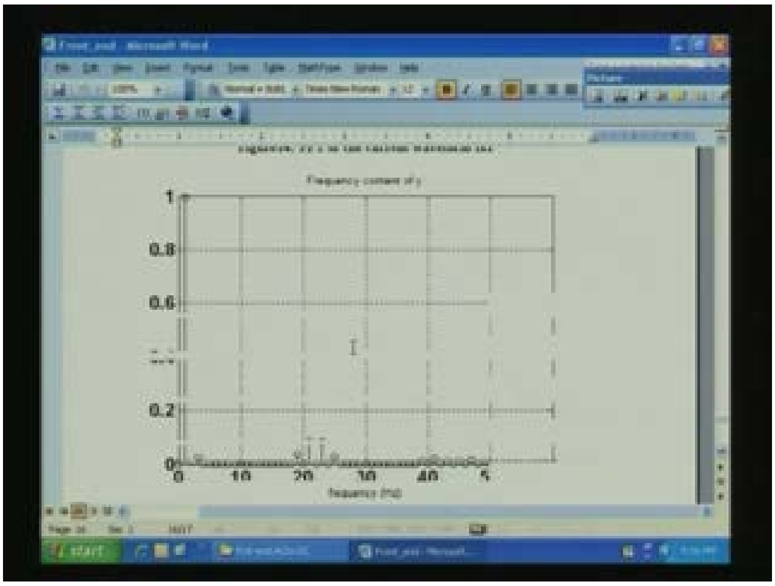

This is for the converter 2 but this is only amplitude, there is a phase difference is there. So, their phase difference is 180 degree.

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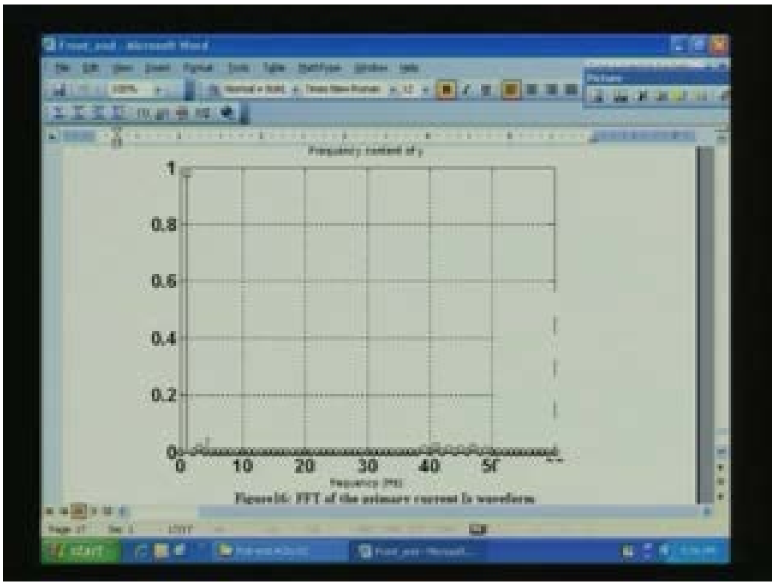

So, if primary if you go primary current that is suppressed and you have the harmonic side bands at 4 f_c and side bands only. So, amplitude is much less.

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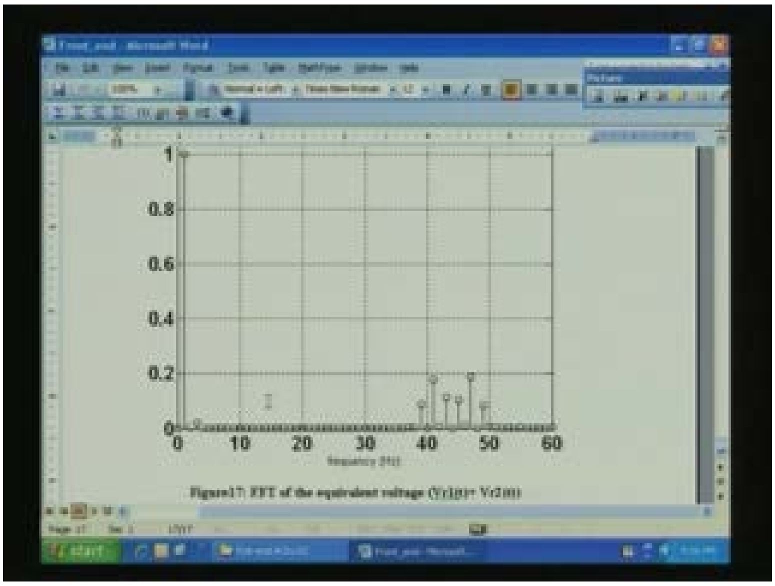

So, this is also visible from the voltage waveform that summed voltage waveform that I showed here. See, this is the equivalent transformer voltage that means we are summing the primary V_{r1} and V_{r2}. So, this is the voltage, this happens at the 4 of it sides in the harmonics. So, what is the advantage here? Even though we are using a carrier frequency of 11 f_c; if it is f_c, it is of 11 f_c somewhere here. But we could shift our high amplitude harmonics to this side not by resorting to high frequency ft, 4 times f_m, f_m is here now, by properly doing a phase shift at PWM control, sine triangle PWM control so that without resorting high frequency PWM switching, we could suppress all the lowered harmonics and the harmonic amplitudes are at high frequency side; this is the voltage.

So, the impedance L, line impedance by L omega is very high for these high frequency voltages. So, current is highly suppressed. So, you have the fundamental and the other current. So, this is the simulation study. So, the approach what I want to say; instead of blindly using P PI controller, there is a way to select the P PI controller. That depends on the system transfer function and its order.

So, first model with the symbol approaches engineering model, we like the way, converter we approximated as the first order lack. So same way, you arrive at the transfer function, various transfer function then link the blocks and get the closed loop. Once the closed loop system is there, you start from the inner loop; you start from the current loop. Then from the current loop, we try to initially start with the PI controller, then try to cancel the pole zero cancellation; it was not working, damping factor was missing. So, any disturbance comes, system will oscillate.

So, with the first order, for a first order lag, how to design the controller? Then we found current loop for the symbol because the whole system goes through only the converter. That converter is represented as the first order lag. So, we require a simple gain controller we require; we found that one and our approximation is correct that is also proved from our simulation study and the various dynamic conditions, results at the various dynamic conditions.

Then we found that current loop is acting very fast and the high frequency, so the current loop can be approximated to the first order lag by removing the S square terms because the next we are inserting this current loop into the voltage loop where the transients are the frequency of the current loop is much lower than the current loop corresponds. So, we we represent as the first order lag and then from the voltage loop, then design our PI controller of the voltage loop here.

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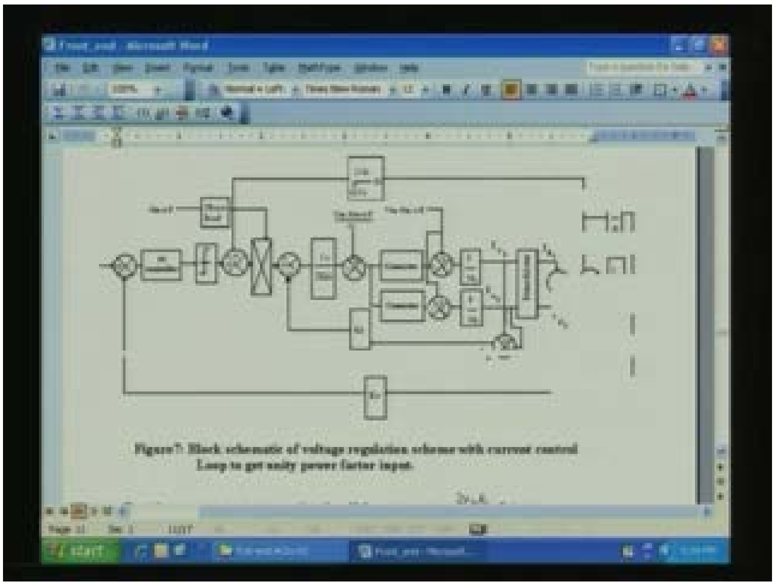

Then the whole system we modelled and simulated and we got the result. So, this approach we can use for other, for not only for front end ac to dc convertor, even for dc motor control or even for induction motor control which we will be studying subsequently and for our not only V by f control, for our high performance application like vector control, we can design same approach.

So, when it when we come to that level, this design approaches we will only mention it because already we have talked about that one, we will use this standard approaches to make use of our controller dc. With this one we will stop and now we have so far studied various controlled rectification; ac to dc you have taken dc to dc converter, then ac to dc converter with unity power factor, so now we can control the voltage with good efficiency good transient performance.

Now, making use of this one, we can go for a dc motor speed control. Here, we will be talking about the separately excited speed control. Then how the speed of the dc motor can be controlled based on the same approach what we have used; we will study in the next few classes.